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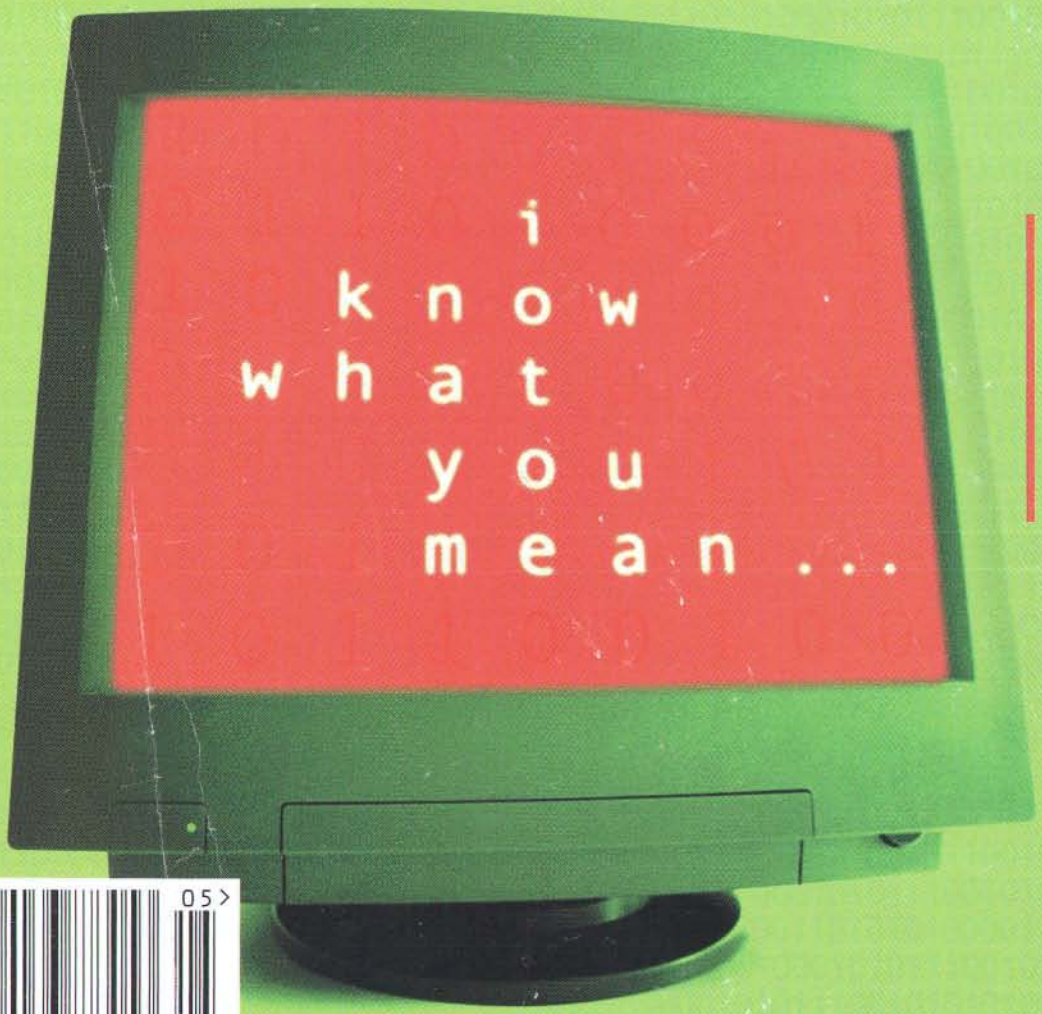

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may 2001

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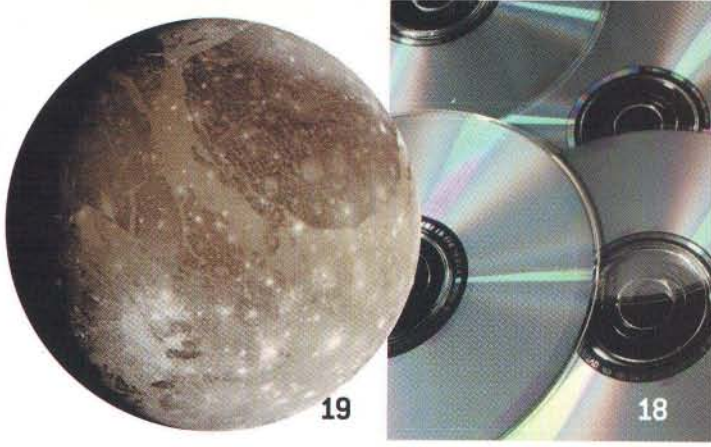
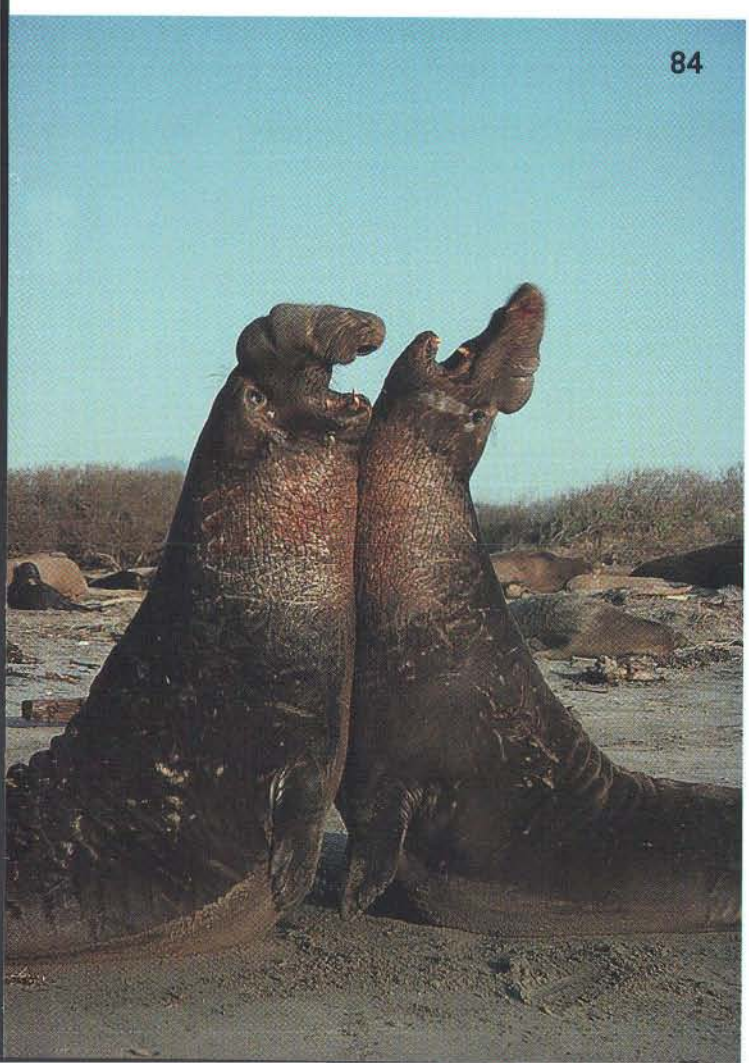




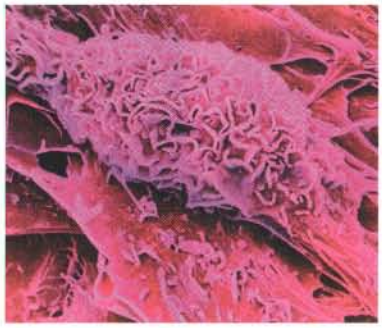
columns

Cover photoillustration by Miguel Salmeron; preceding page: Philip Howe; this page (*clockwise from top left*): Jet Propulsion Laboratory; Steve Allen/The Image Bank; Frank S. Balthis

Save Embryonic Stem Cell Research

We know that embryonic stem cells can differentiate into any tissue of the human body; might they therefore also be able to treat diseases like Parkinson's, Alzheimer's and diabetes? In principle, this ability to differentiate into blood, muscle or neural tissue may make embryonic stem cells the gold standard for replacing bad tissue with good. But some antiabortion advocates, rankled that these cellular chameleons come from embryos, call for a categorical ban on funding this research.

In 1996 Congress forbade the use of federal funds for research that would involve destroying human embryos. Last year, however, the National Institutes of Health issued guidelines, supported by the Clinton administration, that would allow embryonic stem cell research to continue as long as the harvesting step was not conducted with federal monies. In vitro fertilization clinics have been a source of the cells because such clinics regularly discard frozen embryos left over after conception attempts.



EMBRYONIC STEM CELLS

Opponents insist that the NIH is dodging its moral responsibility by letting private clinics do the dirty work. And the Bush administration may be swayed by this argument as it decides whether to overturn the NIH guidelines. Health and Human Services Secretary Tommy Thompson has said that a recommendation on the issue will be announced by late spring or early summer. Eighty Nobel laureates and a variety of research institutions have petitioned the president not to stand in the way of the research. They maintain that a ban will hinder all progress on stem cells and that the U.S. in particular would stand to lose competitiveness in biotech.

Polls have suggested that most of the American public, too, thinks that embryonic cell research should continue, which means that the government must decide how to balance ethical objections from a minority against the wishes of the majority. It would be a mistake to think that the pro-life side has undisputed claim to the moral high ground. Many people question whether it is right to ignore research that offers the best hope for treating or curing so many cruel illnesses.

Opponents of the research might retort, Why not continue using only adult stem cells? Some stem cells can be found in adult tissue as well, after all. The scientific answer is that we don't yet know whether the adult cells necessarily retain the full plasticity of the embryonic ones. Research should and will continue on the adult stem cells, and if they ultimately prove as capable as or better than embryonic ones, it might then be wise to forsake the embryonic cells in deference to the moral debate over whether an embryo is really a human being. Until then, however, adult stem cell work can only be an adjunct to the embryonic work.

No one should too readily dismiss the objections that using embryos in this way is an insult to human dignity. But these were embryos already abandoned by their parents as by-products of other conception attempts. Currently these embryos have exactly zero chance of ever maturing into human beings. Stem cell research offers the cells more opportunity for life than they would otherwise see. It offers many afflicted people an opportunity for healthier, longer lives. Saving embryonic stem cell research may not be an easy choice, but it is the right and moral one.

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Letters

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JANUARY'S SPECIAL REPORT sent some readers into orbit. "I have always considered science a phenomenon that can be created, measured, re-created and potentially disproved," writes Owen W. Dykema of Roseburg, Ore. " 'Brave New Cosmos' is filled with stuff that satisfies none of those criteria. Isn't it time that someone, anyone, reminded us that this is all hypothetical—the hopeful dreams of a few overly optimistic mathematicians?"

Others, though, were practically starry-eyed. Cosmologist Maurice T. Raiford believes "that 'dark energy' will become far more important in the long run than the concept of dark matter. As with atomic physics at the beginning of the past century, in the 21st century, with the application of quantum theory to galactic motion as well as to the universe as a whole, we are already starting to witness a revolution in cosmology."

The shining lights from our in-box are here, in this selection of topics from January 2001.

GETTING TO OMEGA

In "The Quintessential Universe," Jeremiah P. Ostriker and Paul J. Steinhardt refer to measurements of the mass density of the universe, omega, which determines whether the universe is open, closed or flat. The omega in matter is perhaps 0.3, and the cosmological constant is perhaps 0.7. This would give a total omega of 1.0, meaning that we live in a flat universe.

I was under the impression, however, that if the universe is flat, it is so because of the resultant gravitational force. If the force were stronger, the universe would be closed; if weaker, it would be open. Yet to obtain an omega equal to 1.0, it appears that the astrophysicists are adding the energy density of matter (which produces a gravitational force) to the cosmological constant (which produces an antigravitational force). I cannot understand how the addition of a value of 0.3 to –0.7 can result in the answer 1.0.

TOM MOORE
Rowville, Victoria, Australia

STEINHARDT REPLIES: *In Einstein's theory of general relativity, there are two different equations that determine the expansion history of the universe. The first equation, based loosely on the law of conservation of energy, says that the curvature and the current expansion rate depend on the total energy density: the sum of matter and dark energy [quintessence or cosmological constant]. If the sum is equal to the critical density, the universe is indeed flat.*

The second equation, which resembles Newton's second law of motion, describes whether the expansion rate is accelerating or decelerating. That depends not only on the energy density but also on the rate at which the energy density changes as the universe expands. For any gas, the change in energy density when the volume expands depends on its pressure. The pressure of matter is, in the appropriate units, nearly zero, but the pressure of dark energy is strongly negative. If the pressure is sufficiently negative, it causes the universe to accelerate.

MARKETABLE RESULTS VS. GOOD SCIENCE?

David Appell's "The New Uncertainty Principle" [News and Analysis] manages to all but ignore the political and economic corruption of science while inferring an adversarial relationship between scientists and environmentalists. Many environmentalists *are* scientists, albeit often passionately prejudiced ones. Far from being opposed to so-called Frankenfoods, responsible activists target the profit-driven rush to market of inadequately studied

ERIC RISBERG AP Photo

new technologies. Although some of the protesters depicted in the article may disagree, I maintain that the battle is not between science and the environment but rather between good science and bad.

Science has been commodified, and the medium for that commodification is the culture of private-sector funding of scientific research. In the pharmaceutical and biotech industries, scientists are encouraged to produce marketable results, not good science (defined as a disinterested study of a phenomenon with doubts and failures published alongside proofs and successes). Thus, science is not the danger; scientists encouraged to do bad science to survive are. Unfortunately, I think Appell missed that point, because he tries to link Carolyn Raffensperger's line of reasoning to an assertion that research specialization is the smoking gun behind a lack of environmental-impact awareness. Not only is this a non sequitur, it is untrue.

Raffensperger goes on to posit that a code of ethics needs to be reinstated into the scientific community. I don't necessarily think that science currently *lacks* a code of ethics; I think it just knows which side its bread is buttered on. What really needs to change is where the funding comes from. The science of today is too potentially devastating to the environment to be left in the hands of for-profit entities.

Admittedly, changing the way modern science is funded is an enormous undertaking, but it is a necessary one if we want to protect our future. Call it managed risk.

NATHAN SMITH
Oakland, Calif.

ALZHEIMER'S ABERRANT PROTEINS

In "The Cellular Chamber of Doom," Alfred L. Goldberg, Stephen J. Elledge and J. Wade Harper review the role of the proteasome in the degradation of proteins. They briefly mention the accumulation of misfolded proteins in a couple of neurodegenerative disorders and wonder "why the neurons of individuals stricken with these maladies fail to degrade the abnormal proteins." My group at the Netherlands Institute for Brain Research reported in 1998 on a novel process by which ubiquitin itself is crippled as a result of the "molecular misreading" of its gene: during transcription, the ubiquitin gene is misread and the nonsense transcripts are translated into a mutant protein. This aberrant ubiquitin is unable to ubiquitinate other proteins destined for destruction by proteasomes, and it becomes a target for ubiquitination itself. Furthermore, it has recently been shown that mutant ubiquitin blocks the proteasome, thereby acting in a dominant negative fashion. That offers an explanation for why aberrant proteins, such as plaques and tangles in Alzheimer's disease, accumulate in neurodegenerative disorders.

FRED W. VAN LEEUWEN
Amsterdam, The Netherlands

CLARIFICATIONS: Subsequent observations have revealed the "possible protoplanet" in the caption in "Lost Worlds" [George Musser, News and Analysis] to be a star.

William D. Heacox writes "to correct the attribution to me in 'Lost Worlds' that David Black 'is clinging to outmoded ideas' and the implication that I believe that 'extrasolar planets' are indeed planets. In fact, I rather strongly believe that they are more likely to be related to brown dwarfs, and I share Black's opinion that they may reflect a population distinct from either planets or stars."

Jeffrey Wadsworth and Oleg D. Sherby ["Damascus Steels," February 1985] object to the description of their work in John D. Verhoeven's "The Mystery of Damascus Blades." Look for an article by Wadsworth and Sherby to be published this year in *Materials Characterization*.

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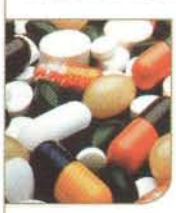

Follow the search for natural remedies. From drugs that fight malaria to those that combat cancer, researchers have discovered a number of potent panaceas outside the lab—in jungles, reefs and deserts. Now bioprospectors are racing to identify even more healing compounds.

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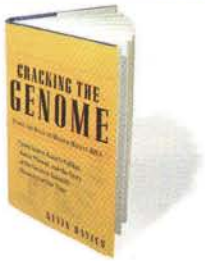


50, 100 & 150 Years Ago

Ill-Fated Viruses ▪ Accepted Electrons ▪ As the World Turns

MAY 1951

VIRUSES—"If one looks around the medical scene in North America or Australia, the most important current change he sees is the rapidly diminishing importance of infectious disease. The fever hospitals are vanishing or being turned to other uses. With full use of the knowledge we already possess, the effective control of every important infectious disease, with the one outstanding exception of poliomyelitis, is possible. As I see it, the main interest of the virus to biology now is the possibility of using it as a probe in the study of the structure and functioning of the cell it infects. —F. M. Burnet, director of the Walter and Eliza Hall Institute of Medical Research, Melbourne, Australia" [*Editors' note: Burnet won the Nobel Prize for Physiology or Medicine in 1960.*]

MAY 1901

THE ELECTRON ACCEPTED—"If Prof. J. J. Thomson's corpuscular hypothesis be absolutely demonstrated, our ideas in regard to chemistry will be revolutionized. In a recent lecture before the Royal Institution, he selected as his subject 'The Existence of Bodies Smaller than Atoms.' When he first enumerated his theory to the scientific world three or four years ago, it was received with considerable incredulity, but has now been adopted by many scientists. He regards the chemical atom as made up of a large number of similar bodies which he calls 'corpuscles.' Prof. Thomson has calculated from the results of his experiments on different substances that the mass of a negative corpuscle is about the five-hundredth part of the hydrogen atom."

LINGUA FRANCA—"Reports from Frankfurt, March 7, 1901, say that the Emperor has decreed that the English language shall be taught in the High Schools of Germany, in the place of French, which shall hereafter be optional."

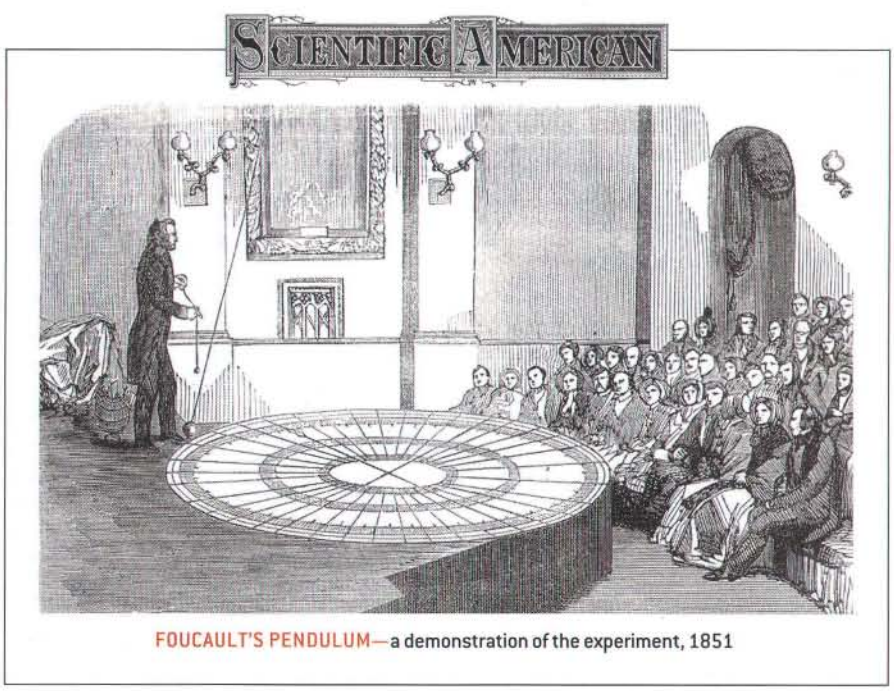
CLIFF DWELLINGS—"The region known as the Mesa Verde, in Colorado, in which there are hundreds of ruins, is to be set aside as a public park, to put a stop to the commercial exploitation of the works of the ancient cliff dwellers. Discovered some twenty-five years ago, the ruins on the Mesa Verde rested for a long time undisturbed and even unvisited, owing to the inaccessibility of the place. Within the past ten years, however, ranchmen living in the vicinity found that specimens from the ruins had a commercial value, and active work began on stripping the remains of all that could be carried off."

MAY 1851

CRYSTAL PALACE OPENS—"It is calculated that there were over 3,000,000 people in the neighborhood of Hyde Park, for the opening of the Great Exhibition by the Queen and His Royal Highness."

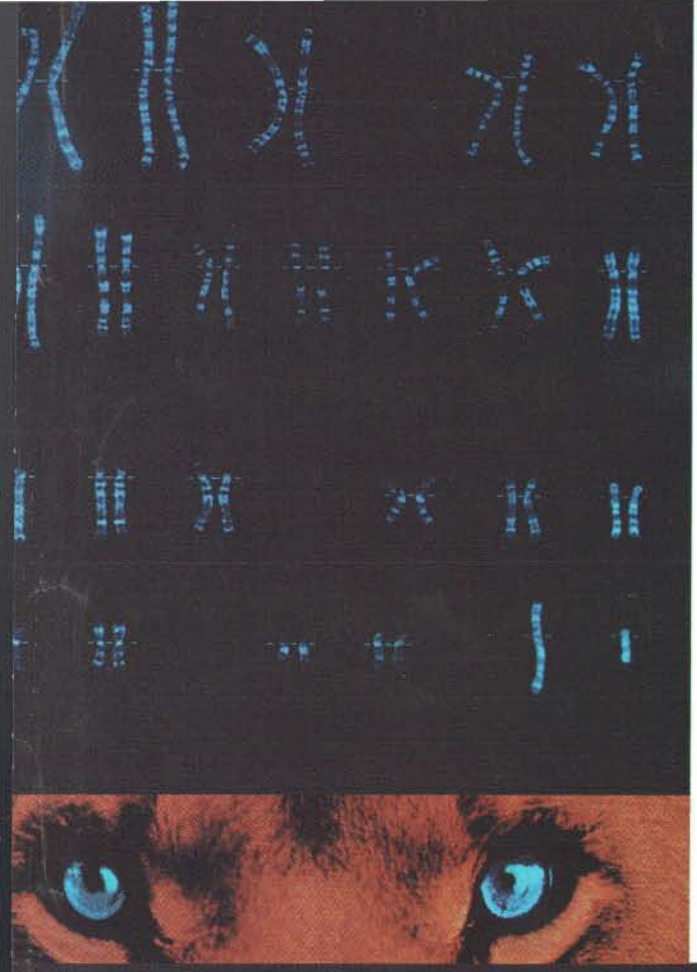
HARD RUBBER—"Patent, to Nelson Goodyear, of New York, N.Y., for improvement in the manufacture of India Rubber: 'I claim the combining of india rubber and sulphur, either with or without shellac, for making a hard and inflexible substance hitherto unknown." [*Editors' note: Nelson's brother, Charles, had invented the process for stabilizing raw rubber in 1839. Manufacturers used hard rubber in things now made of plastic, such as pens and electrical components.*]

FOUCAULT'S PENDULUM—"The accompanying engraving shows Dr. Bachhoffner, at the Polytechnic Institution, London, explaining the experiment of M. Foucault, after the manner employed at the Pantheon in Paris, for demonstrating the rotation of our globe. Fixed to the floor is a circular table, 16 feet in diameter, supposed to rotate with the earth; while a ball, 28 pounds in weight, is suspended by a wire 45 feet long, and vibrates [oscillates] over the table surface. The plane of vibration never changes, but the rotation of the table, and therefore that of the Earth, is visible. The experiment is the subject of much controversy in England, some stating it to be fallacious, others proving it to be the reverse."



FOUCAULT'S PENDULUM—a demonstration of the experiment, 1851

FROM SCIENTIFIC AMERICAN



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EPIDEMIOLOGY

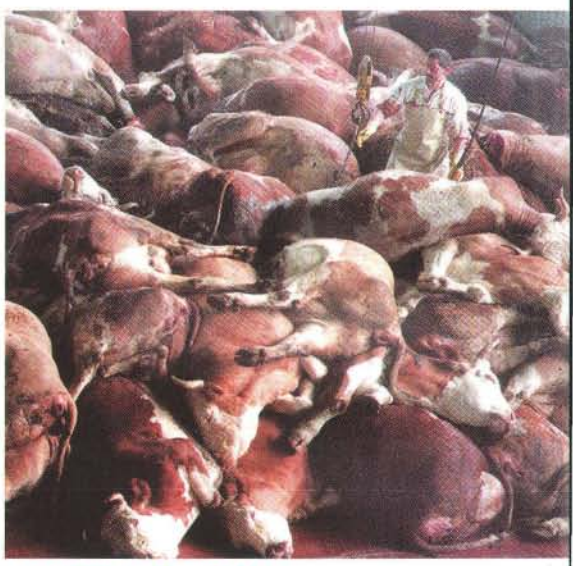
Mad Cow's Human Toll

THE UNFOLDING MYSTERY OF PRION DISEASE AND ITS ULTIMATE CASUALTIES **BY PHILIP YAM**

First, there are feelings of anxiety and depression. A wobbly gait and an uncertain grip soon develop. Within a few months come memory loss, confusion, an inability to recognize familiar faces. Body and mind deteriorate until death occurs. From the symptoms, one might conclude Alzheimer's disease—except that the illness completes its job in about a year, and patients are on average 29 years old. Only an autopsy will reveal, from the spongy mess that was the brain, that the patient died of variant Creutzfeldt-Jakob disease (vCJD)—the human form of the dread mad cow disease.

Since the first deaths in 1995, about 100 people have succumbed to vCJD—the vast majority in the U.K., where 15 died in 1999 and 27 last year, according to the U.K. Department of Health. The illness arises primarily through eating beef tainted by the substance that causes mad cow disease, or bovine spongiform encephalopathy (BSE). Between 1980 and 1996 in the U.K., 750,000 cattle infected with BSE were slaughtered for human consumption, and each cow could have exposed up to 500,000 people. Most of Britain's 60 million residents and untold numbers of tourists may therefore have come into contact with the BSE agent.

But grounding the risk in solid numbers has been nearly impossible, because so little is known about the relentless neuro-invader.



PRECAUTIONARY SLAUGHTERS combat BSE.

FRANK AUGSTEIN *AP Photo*

Researchers are struggling to determine how much of a threat vCJD truly poses and to devise tests that can detect people who may be silently harboring the brain-wasting pathogen.

Unlike other diseases, BSE, vCJD and other transmissible spongiform encephalopathies (TSEs) such as scrapie apparently do not arise from bacteria or viruses—or anything having DNA or RNA. The culprit appears to be malformed versions of protein particles called prions, which normally are coiled into a helix and help to maintain the integrity of nerve cells. In-

A TOUGH LITTLE NEURO-INVADER

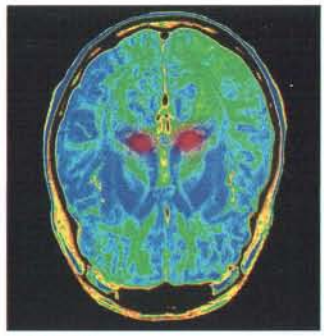
Malformed prions are thought to cause TSEs. But not all the evidence supports this so-called protein-only theory. A few researchers believe some kind of mini virus might be involved, but there has been no evidence of nucleic acids in infectious prions. In any case, the malformed prions are necessary to produce TSE, and getting rid of them is difficult, because the prions

- **Withstand typical cooking temperatures**
- **Are impervious to radiation (one argument against viral involvement)**
- **Resist protease, enzymes that break down protein**

Sterilizing instruments against abnormal prions can be tricky. Autoclaving at 134 degrees Celsius inactivates them, but paradoxically, autoclaving at 138 degrees C does not. A prior soak in sodium hydroxide is recommended.

fectious prions are more sheetlike and somehow coax normal prion proteins to fold into the infectious form.

The incubation time is the key to determining the vCJD toll. (The infectious prions hide out in lymph tissue before assaulting the brain.) One estimate is 10 to 15 years, based on the assumption that the initial cases of vCJD stemmed from the earliest BSE outbreak, which began in the early 1980s and peaked in 1992. Such an incubation length would yield only several hundred vCJD cases, according to a study by epidemiologist Neil M. Ferguson and his colleagues at the University of Oxford. But 136,000 deaths are possible. In that case, "the incubation period of vCJD would have to be large—on the order of 60 years," Ferguson says. "This would make it unusual, but it cannot be ruled out."



A WASTE OF BRAINS: vCJD ravaged the thalamus (*red*) of a 17-year-old patient.

SIMON FRASER/ROYAL VICTORIA INFIRMARY SPL/Photo Researchers, Inc.

Complicating the issue is the unknown lethal dose. Most researchers assume that the more infected beef eaten, the greater the risk. But the type of beef also matters. Processed meats such as sausage may be the riskiest, because they are more likely to contain bits of brain and spinal cord, where prions abound. (One theory of why vCJD strikes younger people is that they consume a lot of processed foods.)

Genetics also plays a role. All vCJD patients thus far have had a particular variation on their prion gene, one that occurs in 40 percent of the Caucasian population. In fact, the Oxford estimates consider only these people. Whether the other 60 percent are immune to infectious prions or can resist them longer is unknown—if the latter, the ultimate number of casualties could jump dramatically.

A huge pool of asymptomatic, or silent, carriers could contaminate the blood supply or surgical instruments, if the experience with the conventional form of CJD, called sporadic CJD, is any indication. This condition results from a rare genetic mutation and is not transmissible the way vCJD is. But it has spread inadvertently through, for instance, the use of growth hormone or corneas taken from infected cadavers. In the U.K., 6.6 percent of sporadic CJD cases have occurred since 1985 because of medical procedures. The only surefire diagnostic, says Bruce Chesebro, a viral epidemiologist at the Rocky Mountain Laboratories in Hamilton, Mont., is to examine brain sections.

Hence, many investigators are working on simple diagnostics, such as blood tests. It won't be easy. "There may not be enough prion protein in the blood to detect," notes Paul Brown of the National Institute of Neurological Disorders and Stroke. But picking out the infectious prions and then amplifying them to more obvious levels may be feasible. Last fall neuropathologist Adriano Aguzzi of the University of Zurich and his colleagues discovered that plasminogen, a natural blood component, clings to infectious prions but not to normal ones. Other researchers claim to have made antibodies that do the same thing. Alternatively, indirect markers of infection may exist: TSEs lead to a drop in the expression of a protein factor in precursor red blood cells.

A convenient diagnostic might enable what Aguzzi calls "postexposure prophylaxis"—preventing infectious prions from reaching the brain. "There are many possibilities one can think of to interfere with prion spread," comments Aguzzi, whose group has found a molecule from spleen cells that keeps prions from moving out of the gut. Researchers can "design little pieces of protein similar but not identical to prions to get in the way" of infectious prions, Brown suggests. Such approaches are more pragmatic than a cure, Aguzzi says, because by the time vCJD symptoms show, "the brain is a mess. There's so much damage, it's not realistic that something can be done with the current medical technology."

Strict controls on rendering throughout Europe—most notably, banning mammalian protein in ruminant feed—have reduced BSE cases dramatically. Violations, however, still pose a hazard: earlier this year two German abattoirs lost their licenses for mixing spinal cord material with feed.

Such lapses are the only way the U.S. would see BSE, Brown thinks. "I am convinced we do not have BSE in this country," he states. "If these regulations are followed strictly, we never will." But mistakes happen: the government reported in January that about 25 percent of U.S. renderers were being lax, such as not labeling feed properly. And considering the popularity of global travel, a case of vCJD in the U.S. may be only a matter of time.

BREACHING THE SPECIES BARRIER

Cows probably first got BSE by eating feed containing rendered, scrapie-infected sheep. In the U.K., several dozen cats came down with a feline version of BSE after eating infected pet food. (Fortunately, none of the families with the cats appear to have contracted infectious prions.)

In the U.S., there's a slim chance that a TSE called chronic wasting disease (CWD), seen in wild elk and deer in the Midwest, could find its way to cattle or to humans. In some areas, the CWD infection rate runs about 18 percent—some five times higher than BSE at its worst in the U.K. "Some in the U.S. may be being a little naive" about CWD, warns Adriano Aguzzi of the University of Zurich, because no one knows how it spreads in the wild. Moreover, studies have shown that CWD could infect cattle, albeit only when the diseased tissue is injected into the brain. But Paul Brown of the National Institute of Neurological Disorders and Stroke notes that CWD has been around for decades and has not spread or led to a single case of vCJD, even among hunters who may have eaten infected animals. "I'm not particularly worried about a wildfire spread, given the history," Brown says.

CONSERVATION

Troubles at the Edge

AT THEIR BORDERS, RESERVES MAY INCREASE ANIMAL DEATHS BY LUIS MIGUEL ARIZA

DOÑANA NATIONAL PARK, SPAIN—While driving along a sandy road on the northern part of the National Park of Doñana, in southwest Spain near Seville, Francisco Palomares outlines the glaring difference between the two habitats that run on either side. To the southeast is open pastureland; closer to the fences is a scrub zone called Coto del Rey, which also abounds with cork trees and pines growing up to four meters high. Not visible is the marshland farther away, toward the east at the park's core. The diverse environments probably make Doñana the richest reserve in Europe, attracting some 400 species of birds and several types of wildcats, deer and other mammals. Yet ironically, reserves such as this one may be doing more harm than good, at least on their margins. That conclusion is based on the population of the Eurasian badger (*Meles meles*), which has been decreasing because of poachers drawn to the reserve in search of easy pickings. In fact, in some places there are fewer badgers on the inside of the fenced-in park than on adjacent areas outside.

BADGERED: *Meles meles* suffers because of incidental poaching.

The badgers themselves are of no interest to the poachers, who aim for red deer and other wild game abundant on the pasturelands. Those areas are the "killing fields" for the badgers, says Palomares, a biologist at the Estación Biológica of Doñana-CSIC. At night, the animals leave the safety of the scrubs to hunt on the open lands and find themselves at the mercy of hounds unleashed by the poachers during their nocturnal raids. "We have seen entire families wiped out this way in a matter of only a few months," Palomares states.

In an extensive study conducted between 1985 and 1997, Palomares and his colleagues Miguel Delibes and Eloy Revilla radio-tagged 33 Doñana badgers within an area spanning 550 square kilometers. One group of badgers belonged to the five territories in Coto del Rey; the others resided within the core of the park, Reserve Biológica. Of the tagged badgers, the team recorded 13 deaths, attributable mainly to the poachers. The researchers also found seven other casualties, one of which died in the reserve. In total, 80 percent of the accidentally poached badgers were within the park boundaries.

Although the reserve protects badgers overall—there are more of them in the core of the park than outside it—populations at the park's margins are actually lower than on the outside. "We found the extinction of badger populations in some zones of the edges, and those that had fled there died soon after," reports Revilla, the study's lead author, who spent more than 100 nights tracking the animals. He found that the critical variable for predicting the survival of an individual is the distance from the border: three kilometers in from the boundaries, there were far fewer deaths at human hands.

Revilla says the findings, which were published in the February issue of *Conservation Biology,* may lead to more effective park designs. The more border areas there are, for instance, the less secure the refuge. That would be especially true for carnivores with large ranges, such as the Iberian lynx, which may cruise 20 kilometers a day. Revilla warns that "edge effects can make reserves useless for carnivores that need larger habitats and can accelerate their extinction."

But whether the conclusions can be extended from badgers to other species is hard to say. Delibes notes that the hounds of poachers wouldn't be able to catch bigger, faster carnivores such as lynx. And despite other threats on the perimeters—from cars and illegal coil-spring traps meant for foxes and rabbits—the animals stand a better chance thanks to the park.

Luis Miguel Ariza is a science writer based in Madrid.

RESERVATIONS ON RESERVES

The results of the Spanish research do not imply that reserves have a negative net effect on conservation, notes Joshua Ginsberg, director of the Asia Program of the Wildlife Conservation Society in New York City. "What is known from numerous studies is that reserves are absolutely critical to the conservation of carnivores and that larger carnivores need larger reserves." Reserves that lead to deaths do not mean they are in themselves bad but that protection is poor. "Protection is critical to reserve integrity where people do not respect the laws."

HANS PFLETSCHINGER *Peter Arnold, Inc.*

Deeper Impact

WAS YET ANOTHER MASS EXTINCTION THE WORK OF AN ASTEROID? BY SARAH SIMPSON

Mention "asteroid" or "comet," and the fire-and-brimstone fantasy of an earth-shattering collision will pop into many people's minds. Two thirds of the planet's species, including the dinosaurs, died in the aftermath of one such impact 65 million years ago. But that was a minor tragedy compared with the catastrophic extinction that swept the globe 185 million years earlier. At that time, 95 percent of life in the oceans vanished forever—and surprising new evidence points to a similar cosmic killer.

Researchers long assumed that gradual changes in climate or sea level prolonged that mass death, which marks the boundary between the Permian and Triassic periods, over half a million years or more. But last year paleontologists who examined marine fossils from Austria and China reported that the doomed Permian creatures disappeared in 8,000 years or less—a sudden death in geologic terms. No compelling culprit turned up until early March, when the news of possible extraterrestrial involvement appeared in *Science*. Luann Becker of the University of Washington, Robert J. Poreda of the University of Rochester and their colleagues extracted strange traces of helium and argon from rocks at the site in China and at a third locale in Japan. Helium and argon, both noble gases, exist naturally inside the earth and its atmosphere, but the isotopic signatures of the gases in these particular rocks require a cosmic origin.

RON MILLER

VIOLENT ENCOUNTER could explain the traces of cosmic gas associated with a massive die-off 250 million years ago.

"I don't see any way of creating [the gases] on earth," says Sujoy Mukhopadhyay, a noble gas geochemist at the California Institute of Technology. So they must have hitched a ride on an earthbound asteroid or comet, Becker and her colleagues reasoned. They further suspect that the gases survived the violent encounter by being encapsulated within tough cages of carbon atoms called fullerenes. "The original idea was that the gases in these fullerenes should reflect the isotopic composition of the ancient atmosphere," Poreda says. "We were very surprised when they resembled [extraterrestrial] rather than atmospheric gas." His team shored up its argument by also detecting fullerenes in two meteorites. Other workers have found them associated with the Cretaceous-Tertiary (K-T) impact.

Despite the fullerene frenzy, the case for a Permian-Triassic (P-T) impact is far from closed. "This is tricky stuff, and until it is confirmed there is little reason to get too excited," says paleontologist Douglas H. Erwin of the Smithsonian Institution. The most reliable tracers of the K-T impact (other than the suspected crater, located in eastern Mexico) are iridium enrichments and quartz grains scarred by the intense heat and pressure of the massive blow. In 1998 Gregory Retallack of the University of Oregon and his colleagues found similar tracers at P-T sites in Antarctica and Australia. But the iridium enrichments are only about one tenth of those at the K-T sites, and the fragments of shocked quartz are smaller. These findings counter the expectation, Irwin says: "Given the much larger magnitude of the P-T extinction, the impact would have had to be far larger than the K-T impact."

Becker points out that if an object the size of the K-T impactor hit the deep ocean rather than land, less iridium would have been released into the air. And because the ocean crust contains little quartz, Retallack says, traces of the shocked variety would be minimal. Still, Retallack concedes that an impact alone probably did not do the P-T damage, yet he asserts that a small space rock can pack a mean punch.

TOP FIVE MASS EXTINCTIONS

Permian-Triassic
Date: About 250 million years ago
Death Toll: 84 percent of marine genera; 95 percent of marine species; 70 percent of land species
Possible Causes: Asteroid or comet impact; severe volcanism; dramatic fluctuations in climate or sea level

Cretaceous-Tertiary
Date: About 65 million years ago
Death Toll: Up to 75 percent of marine genera; 18 percent of land vertebrates, including dinosaurs
Possible Causes: Impact; severe volcanism

Late Ordovician
Date: About 440 million years ago
Death Toll: 60 percent of marine genera
Possible Cause: Dramatic fluctuations in sea level

Late Devonian
Date: About 365 million years ago
Death Toll: 55 percent of marine genera
Possible Causes: Global cooling; loss of oxygen in oceans; impact

Late Triassic
Date: About 200 million years ago
Death Toll: 52 percent of marine genera
Possible Causes: Severe volcanism; global warming

Retallack's earthly rocks, which record the history of Permian river basins, reveal an intense spike of light carbon values—a telltale sign of a greenhouse warming crisis—during the extinction. More specifically, the carbon values indicate that the atmosphere was loaded with methane. Tons of this potent greenhouse gas could have been released instantly if the offending space rock slammed into a deposit of methane hydrate, Retallack says.

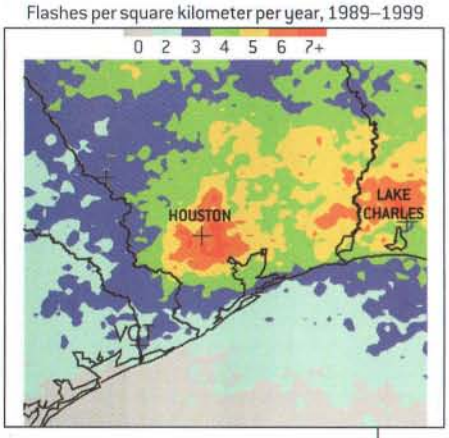
In the end, scientists may be forced to rely on tracers such as fullerenes to prove whether an impact prompted the world's worst mass extinction. "I have a feeling we're either going to go down in flames," Becker says, "or we're going to be heroes."

METEOROLOGY

Bright Sky, Dirty City?

HOUSTON, WE HAVE GROUND STRIKES. LOTS OF THEM

BY STEPHEN COLE



LIGHTNING-FLASH DENSITY is high over Houston and Lake Charles, La.

To look at the false-colored U.S. map of cloud-to-ground lightning flashes over the past decade, you would think that someone had planted a huge lightning rod in the middle of Houston. During peak thunderstorm season (June to August), the city is hit by an average of 1,700 ground flashes a month—only areas in Florida are hit worse. And there are twice as many ground strikes over and immediately downwind of Houston as there are upwind just 80 kilometers away.

"Somehow 4.5 million people are having a major effect on the meteorology of Houston," says Richard Orville of Texas A&M University, lead author of a paper to be published in *Geophysical Research Letters*. The researchers relied on the National Lightning Detection Network, a database that pinpoints ground flashes with unprecedented accuracy. A 1995 study of 16 Midwestern U.S. cities used these data and found a correlation between city size, air pollution and lightning, but it could not single out one factor responsible for the extra lightning, which was generally much less than in Houston.

The new research seeks to narrow the possibilities. Local meteorological conditions produced by nearby Galveston Bay, which enhances convective activity and thunderstorm development, can be counted out, Orville believes. The researchers simulated the meteorology of the region with and without Houston's urban elements and found that the strong patterns of convergence over the city were not caused by the bay but by the "heat island effect" of the city itself.

But urban heat may not be the whole story. Orville's analysis also found a lightning hot spot over Lake Charles, La., just east of Houston. Ground flashes over this small city reached levels as high as Houston's, but there is no urban landscape to fuel them.

One thing the two cities share is major air pollution sources, including petroleum refineries. Renyi Zhang, an atmospheric chemist at Texas A&M, says that air pollution particles, or aerosols, could boost lightning by helping more cloud water get into the upper reaches of a deep convective cloud, where supercooled water droplets collide with ice crystals. "The particle collisions act just like rubbing your hand through your hair to separate electric charge," Zhang says.

Daniel Rosenfeld of the Hebrew University of Jerusalem recently reported observations in the Brazilian Amazon of how aerosols can boost lightning: smoke particles from biomass burning create many small cloud droplets that carry more water high into the cloud.

Here, too, separating the effect of aerosols from other related factors isn't easy. "This supercooled water can get high in the clouds by stronger updrafts or with the help of aerosols," Rosenfeld explains. "Usually the stronger updrafts are also in the more polluted air."

Orville plans to take a closer look at both Houston and Lake Charles. With the wealth of high-resolution lightning data in hand, he hopes to pinpoint the reasons why Houston's skies are so often bright.

Stephen Cole is a science writer and editor based in Washington, D.C.

NEED TO KNOW: CHARGED UP

Last year the Environmental Protection Agency funded a "supersite" monitoring program in Houston to study the sources and composition of its particulate pollution.

The National Lightning Detection Network records ground flashes every microsecond and locates the strikes to within less than a kilometer.

Rather than pollution or the heat island effect, Florida experiences a lot of lightning because of its peninsular geography and subtropical climate, which help to make it the undisputed lightning champ from coast to coast.

COURTESY OF THE LIGHTNING PROJECT, TEXAS A&M UNIVERSITY

HEALTH

Taken to Heart

BRUSHING YOUR TEETH MAY BE GOOD FOR YOUR TICKER **BY JULIA KAROW**

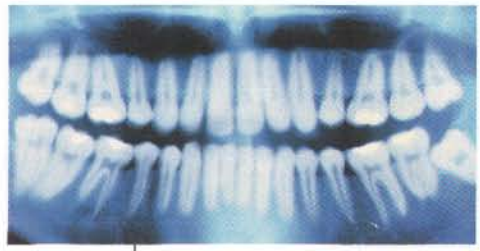
Coronary heart disease, the leading killer in the U.S., is mostly related to smoking, lack of exercise and too many visits to the greasy spoon. But recently infection has joined the list as a possible risk factor. In particular, some studies suggest an association between infected gums and heart disease, and oral bacteria have even shown up in the sticky plaques lining diseased arteries. If a causal relation can be established, then treating gum disease early may prevent hundreds of heart attacks every year.

At least half of all Americans over age 30 have gingivitis, a mild inflammation caused by bacterial plaque. Untreated, it may turn into periodontitis, in which bacteria colonize pockets that form between the gums and teeth. The resulting inflammation slowly eats away tissue and bone, eventually leading to tooth loss. At least one third of U.S. adults over age 30 have some form of periodontitis (smoking is a main risk factor for getting it).

Acute periodontitis may lead to heart disease because it might cause low-level inflammation in the whole body: chemicals produced by the immune reaction in the gum pockets probably spill over into the bloodstream and trigger the liver to make proteins that inflame arterial walls and clot blood. Atherosclerosis and, ultimately, heart attack may result. One such factor, C-reactive protein—a predictor of heart disease—is elevated in patients with periodontitis. Alternatively, the microbes themselves may travel from the mouth and affect blood vessels.

Epidemiological studies, however, are split on the issue. Some studies that claimed a link did not account for factors such as smoking, and two recent prospective studies did not find any association. But some researchers believe that those investigations used too crude a measure for periodontitis. "The real association should be with infection," says Robert J. Genco of the State University of New York at Buffalo. But so far almost every study, whether it found a link or not, relied on either self-reporting or measured bone loss, pocket depth or gum recession—telltale signs of an infection that might be long gone by the time subjects were examined. Even these studies should have picked up a large risk, though; a small but existing link might be difficult to prove at all. Complicating matters are genetic factors that may predispose some individuals to hyperinflammation, leading to both heart disease and periodontitis.

An intervention study might settle the issue: If you treat periodontal disease, will heart disease go down? Researchers from S.U.N.Y. at Buffalo and the University of North Carolina at Chapel Hill will start a pilot program this summer, involving three groups of 300 patients. In the meantime, treating bleeding gums early is not a bad idea in any case. "Your oral health will get better," says James D. Beck of Chapel Hill, and "perhaps other parts of your body will benefit from it also."



HEALTHY TEETH, healthy heart?

FROM YOUR MOUTH TO YOUR HEART

In a recent examination of 50 plaques scraped out of human arteries, 72 percent contained periodontal pathogens. Two other pathogens that are hot candidates for atherosclerosis were also present: cytomegalovirus, which infected 38 percent of plaques, and *Chlamydia pneumoniae*, which appeared in 18 percent. Studies have also found antibodies against oral bacteria in the blood, and animal tests have shown that mouth microbes injected into the blood lead to atherosclerosis. Links between periodontal infection and other illnesses such as diabetes, chronic respiratory disease, stroke and low birth weight have also emerged. They support the theory that many chronic ills stem from infections (see Profile of Paul W. Ewald on page 26).

MATERIALS

Shape-Shifters

SHAPE-MEMORY POLYMERS FIND USE IN MEDICINE AND CLOTHING **BY STEVEN ASHLEY**

Special plastic materials able to change shape in response to temperature may soon find applications in a variety of extreme climes—from the warm, moist environs of human blood vessels to cold, wet and windy mountaintops. These plastics have a "memory" that allows them to be deformed into a temporary configuration and then be restored to the original parent geometry by applying heat. Shrink-wrap is perhaps the

UHB TRUST Stone

MATERIAL METAMORPHOSIS: When heated, biodegradable shape-memory polymer transforms from a temporary shape (*left*) to its parent shape (*right*) within 20 seconds.

most familiar example of a shape-memory polymer (SMP). But since the mid-1980s chemists, materials scientists and engineers have been working to develop SMPs as a kind of "smart" material—a substance that can respond to environmental changes as desired.

Shape-memory substances are not new: certain metallic compounds exhibited the effect in the 1930s, and alloys such as nickel-titanium (Nitinol) have since found use in actuators and medical devices such as dental braces and endovascular implants. These metals switch from a temporary to a parent shape above a certain transition temperature. Below that temperature, the shape-memory alloy (SMA) can be bent into various configurations.

Although SMAs have found relatively wide application, they have some serious drawbacks, says Andreas Lendlein, a polymer researcher at the German Wool Research Institute in Aachen. "Besides being comparatively costly, SMAs have a maximum deformation of only about 8 percent," he notes. In addition, "SMA programming is time-consuming and involves high temperatures." Lendlein adds that the mechanical properties of SMAs can be adjusted within only a limited range and that they are not biodegradable.

Shape-memory polymers, in contrast, offer much greater deformation capabilities, substantially easier shaping procedures and high shape stability, he contends. SMPs also have an advantage in that their transition temperatures and mechanical properties can be varied in a wide range with only small changes to their chemical structure and composition.

The remarkable properties of SMPs, Lendlein says, are based on two key structural features: "triggering segments that have a thermal transition within the temperature range of interest, and cross-links that determine the permanent shape." Depending on the type of cross-links, SMPs can be either thermoplastic elastomers (which soften when heated and harden when cooled) or thermosets (which solidify after being heated and cooled and cannot be remelted).

To exploit SMPs, Lendlein and Massachusetts Institute of Technology chemical engineer Robert Langer established mnemoScience in 1997, a firm that believes biodegradable SMPs are just the thing for minimally invasive surgery. Previously large and bulky implants could be converted into small devices that are precisely positioned using endoscopes and then expanded to fit the needs of the body, Lendlein explains. These devices will degrade within a predetermined time, making a second, follow-up surgery unnecessary. In the case of stents, the endovascular implants that expand to keep diseased blood vessels open, "it would be helpful if they were to just disappear after a time, allowing the unobstructed tissue to fully heal," he says.

The shape-memory effect has also developed in what are called linear block copolymers, which feature a segmented structure. At Mitsubishi Heavy Industries in Nagoya, Japan, Shunichi Hayashi's research team has created segmented polyurethanes that have the hard segments needed to form the points for physical cross-linking and soft segments responsible for the shape-memory capabilities.

The shape-recovery temperature of these polyurethanes can be tailored from –30 to 70 degrees Celsius or warmer. Although these materials also offer improved easy processability, excellent chemical properties, biocompatibility, relatively low cost and the capability of 400 percent shape recovery, one disadvantage is low recovery force. Applications must be limited to situations in which the SMP device need not push hard against any obstacle.

Via a subsidiary, Mitsubishi is marketing a segmented polyurethane-based fabric for "intelligent" cold-weather clothing under the name Diaplex. The nonporous material's microstructure opens up to allow passage of heat and humidity when ambient temperatures rise. Several severe-weather clothiers also have developed similar SMP-based fabrics.

Some researchers think that self-repairing SMP objects, such as auto panels, may soon be developed: simply park a car in the hot sun, and the dents will iron themselves out.

TOTAL RECALL FOR MARTIAN POLYMERS

Shape-memory polymers could pull space duty. Witold M. Sokolowski, research engineer at the Jet Propulsion Laboratory in Pasadena, Calif., is using Mitsubishi's SMP polyurethane in expendable, self-deploying structures. Using an open cellular foam form of the polymer, he and his co-workers have already demonstrated the feasibility of making compact polyurethane wheels for future robotic planetary rovers. The wheels arrive compressed and then expand to size with exposure to solar heat. "These structures are very simple and reliable," says Sokolowski, who originated the concept, "a real improvement over mechanically deployed structures, which are unreliable, heavy and bulky."

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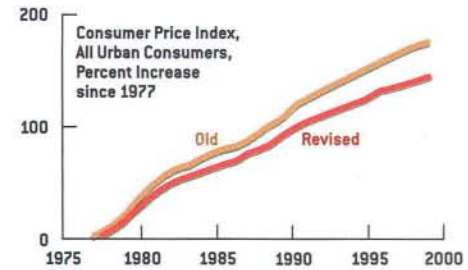
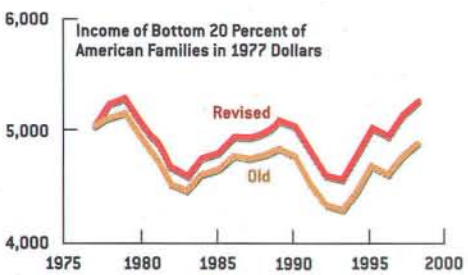
Rewriting History

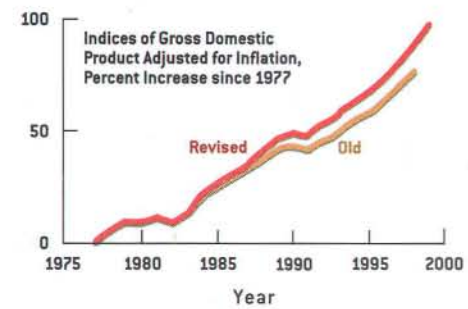
HOW STATISTICAL REVISIONS COLOR OUR VIEW OF THE PAST BY RODGER DOYLE

Oscar Wilde said that "the one duty we owe to history is to rewrite it," and that is precisely what agencies such as the U.S. Bureau of Labor Statistics do as a matter of course. In 1999 the BLS made another in its series of major revisions to the consumer price index. The CPI is the key to calculating Social Security cost-of-living increases and adjusting federal income taxes to prevent "bracket creep," the problem that arises when taxpayers are pushed into a higher bracket because of inflation. Such revisions, of course, don't result in retroactive benefits, but they do change our perception of the past in meaningful ways.

The new CPI, adjusted retroactively to 1977, takes into account the cumulative effect of many small improvements in methodology made over the past two decades. For instance, it compensates for the rise in the durability of automobiles, which, it is assumed, partially offsets price increases. The new CPI also takes into account the substitution of generic for name-brand drugs as the patents of the latter expire. None of these improvements alone is important, but cumulatively they are significant, as illustrated in the chart comparing the old and revised CPI.







AARON FIRTH

One way in which revision of the CPI can affect judgment of the past can be seen in the chart showing average income for the bottom fifth of all families. The new CPI data show that the poorest American families had a higher family income in 1998 than in 1977, rather than a lower income, as was indicated by the old data. The difference may not seem great, but it is important to the families involved and to economists arguing over the "high tide raises all boats" theory.

The gross domestic product, produced by the U.S. Bureau of Economic Analysis, also underwent critical revisions, which took into account a number of technical changes as well as adjustment for inflation based on the consumer and producer price indices. The revised figures reveal GDP growing considerably faster than was indicated by the old figures. Using the old data, an economist might predict that the economy would grow by 33 percent over the next 20 years, but with the new figures the same economist might predict 40 percent growth, a difference that has huge implications for fiscal policy.

If it seems to you that "reality" in the social sciences is a slippery concept, you are not far wrong. Economic relations, personal habits and technology are changing so rapidly that statisticians must constantly devise new ways of measurement if they are to avoid data degradation. The implication is that major revisions of federal statistics will be with us as long as the U.S. maintains a dynamic economy.

Rodger Doyle's e-mail is rdoyle2@aol.com

news SCAN

NEED TO KNOW: VITAL CHANGES

Statistics of a much different kind—mortality data produced by the National Center for Health Statistics, part of the Centers for Disease Control and Prevention—have also undergone a number of significant revisions. Under the protocols of the *World Health Organization's International Classification of Diseases, 10th Revision*, which went into effect in the U.S. with the 1999 data, the NCHS has substantially changed the data for many causes of death. A notable one is Alzheimer's, which will jump by at least 55 percent above the level reported for 1998. This increase does not reflect a sudden surge in mortality but a change in classification, which nonetheless will have a substantial bearing on the epidemiology of the disease.

DATA POINTS:

THE NOT SO SHELTERING SKY

Average annual tornado damage cost in the U.S.: $1.103 billion
Highest-ranking state: Texas ($88.6 million)
Lowest-ranking state: Alaska ($1,000)
North American box-office revenue for *Twister*: $240 million

Average annual flood damage: $5.942 billion
Highest-ranking state: Pennsylvania ($682.3 million)
Budget for *Waterworld*: $175 million
Where it would rank among the 50 states in terms of damage costs: 12

Hurricane damage calculated on average annual basis: $5.1 billion
In Massachusetts: $70.8 million
Worldwide box-office revenue for *The Perfect Storm*: $323 million

SOURCES: Extreme Weather Sourcebook, 2001; Entertainment Weekly *(Collector's issue, March 1997)*; Variety *(April 29, 1996, and January 15, 2001)*. *Costs are in 1999 dollars. Unlike tornadoes and flooding, hurricanes occur too sporadically to provide meaningful annual damage estimates; total spent between 1900 and 1999 is $510.6 billion in U.S. and $7.08 billion in Massachusetts.*

COMPUTERS

Hack Job

DECRYPTED AGAIN ... and again

The debate over DVD encryption is getting hotter. In March, coders released two computer programs that unscramble CSS, the content-scrambling system designed to prevent unauthorized copying of DVDs. The programs, elusively named "qrpff" and "efdtt," are only 526 and 442 bytes, respectively, and both appear on a Web site hosted by Carnegie Mellon University computer scientist David Touretzky. In all likelihood, qrpff and efdtt, like the longer, well-known decryption program DeCSS, violate the Digital Millennium Copyright Act, which designates any program that removes copyright-protection mechanisms as illegal. But qrpff authors Keith Winstein and Marc Horowitz of M.I.T. say they wanted to illustrate the futility of DVD-encryption technology and the right to devise programs that subvert it. "You can write these seven lines of code on a piece of paper and give it to someone," Winstein told CNET. "It's ridiculous to say that that's not protected speech." —*Alison McCook*

TISSUE ENGINEERING

Fat into Cartilage

Not much can be done to repair joints rendered creaky by deteriorating cartilage. With a minimal blood supply, cartilage doesn't fix itself very well, and treatments that coax new cartilage growth are expensive. But flab may be fab, announced researchers from Duke University and the tissue engineering firm Artecel at the February meeting of the Orthopedic Research Society. From liposuctioned fat, the team derived so-called stromal cells. A brew of chemicals that included steroids, growth factors and vitamin C transformed the stromal cells into cartilage. Clinical trials to assess whether the fat-turned-cartilage could work for human joints, however, wouldn't begin for at least several years. —*Philip Yam*

PSYCHOLOGY

Holier Than Thou

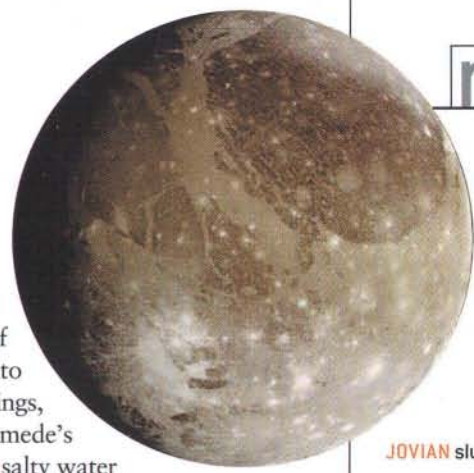
HOW MUCH would you donate?

It's no secret that people tend to think more highly of themselves than they think of others, and a study in the December 2000 *Journal of Personality and Social Psychology* suggests that the tendency stems from our inability to predict our own behavior accurately. Nicholas Epley and David Dunning of Cornell University described an experiment in which students predicted that they would give to charity about half of their $5 study-participation reimbursement but that their peers would fork over only $1.83—yet the average donor gave $1.53. Epley and Dunning's more recent research, not yet published, suggests that this overestimation applies to behaviors beyond those associated with ethics and morality. In an experiment before the last presidential election, 84 percent of eligible voters said they would cast their ballot but predicted that only 67 percent of others would. At election time, only 68 percent of subjects actually voted. "Self-insight is harder to come by than people realize," Epley says. —*Alison McCook*

PHOTOGRAPHS BY STEVE ALLEN *The Image Bank (top)*; CHRIS THOMAIDIS *Stone (bottom)*; ILLUSTRATION BY MATT COLLINS

ASTRONOMY

Otherworldly Ocean



JOVIAN slush ball

Jupiter's largest moon, Ganymede, is an icy playground made up of bright bands of smooth frozen water. Recent stereo images compiled from the Voyager and Galileo spacecraft reveal that the brightest bands lie in troughs up to half a mile lower than the darker, more cratered regions. This topography suggests that the bands originated from volcanic eruptions of water or slush, which flooded the depressions and then froze into the smooth strips that now cover much of the moon. These findings, in the March 1 *Nature,* support a recent analysis of Ganymede's magnetic field that suggested that the moon harbors a layer of salty water several miles thick, within 120 miles of the icy crust. One billion years ago, when the eruptions occurred, this ocean may have resided closer to the surface. —*Alison McCook*

PHYSICS

Microscopic Maelstrom

Facing 1,500 g's sounds like the kind of acceleration an intrepid explorer might experience on venturing too close to a black hole. But according to the February 22 *Nature,* such extraordinary accelerations occur within turbulent water. Eberhard Bodenschatz, Jim Alexander and their coworkers at Cornell University tracked the movements of 50-micron-diameter polystyrene spheres in water churned up by two counterrotating disks. The particles accelerated from zero to up to 1,500 g's and back in fractions of a millisecond. To achieve such unprecedented high resolution, the group adapted a high-energy particle detector from the Cornell Electron Positron Collider. The results agree with predictions made in the late 1940s by Werner Heisenberg and Akiva M. Yaglom. Turbulent flows play an important role in industrial chemical reactors, combustion, the formation of clouds and the dispersal of pollutants. —*Graham P. Collins*

TURBULENCE confirmed

MEDICINE

Fetal Cell Setback

Parkinson's disease results from a gradual loss of the brain cells that produce dopamine, the neurotransmitter needed for normal movement. Anecdotal evidence suggested that implanting dopamine-generating cells from fetuses into afflicted brains might help. But the first in-depth clinical study to assess fetal cell transplants has yielded some unfortunate results. Although fetal cells grew in the brains of 85 percent of the transplant patients, and those younger than 60 showed some signs of improvement one year after surgery, 15 percent of these younger patients eventually began exhibiting extreme—and irreversible—side effects, such as uncontrollable writhing and jerking. And none of the transplant patients older than 60 reported any improvement. While noting the failures of the experiment, described in the March 8 *New England Journal of Medicine,* the researchers suggest that a better understanding of dopamine's role in the brain and improvements to the surgical procedure, such as inserting the cells into different regions, may yield more promising results.

—*Alison McCook*

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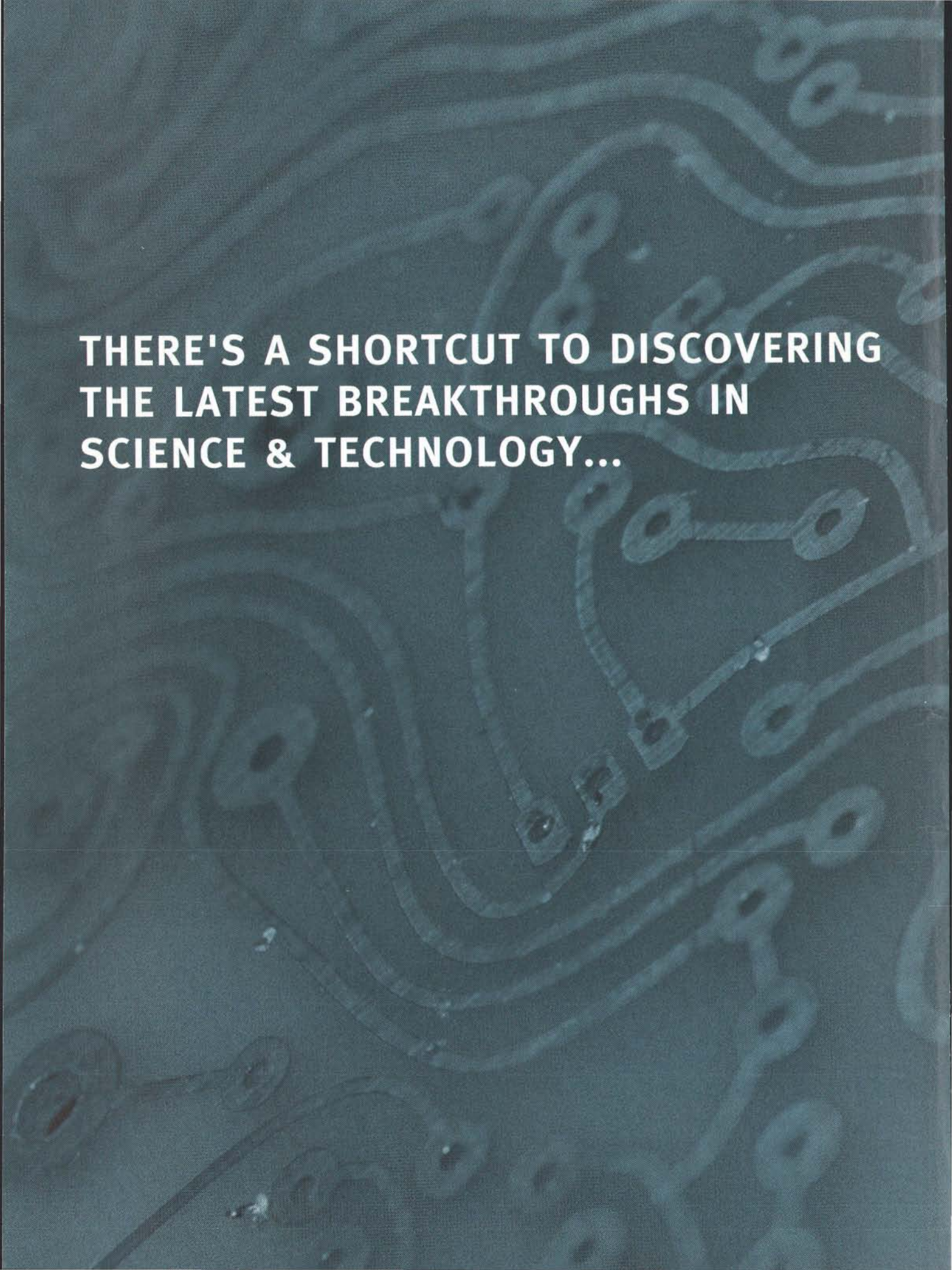
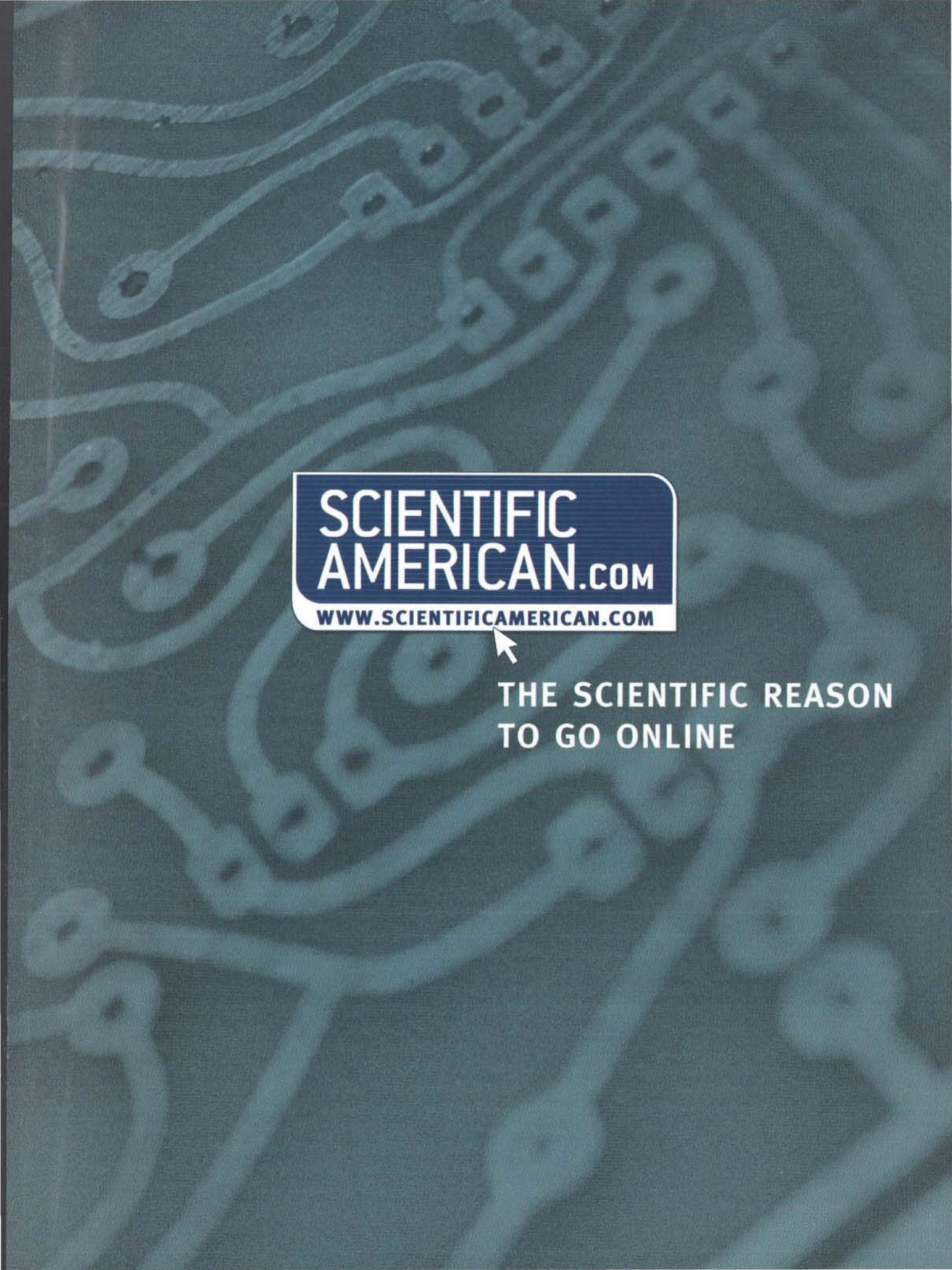
BRIEF BITS

- **Rates of dyslexia may be influenced by the complexities of certain languages—Italy's rate is about half that of the U.S.** /031601/2.html
- **A new type of quasar, one surrounded by dust and gas clouds, has been discovered.** /031401/3.html
- **Women prefer wimps? Female cockroaches seek low-status males, even though the couplings produce fewer sons as a result.** /030701/3.html
- **Thanks to climate change and irrigation, Lake Chad, one of Africa's biggest freshwater bodies, has shriveled by 95 percent since 1963.** /030101/4.html

PHOTOGRAPHS COURTESY OF JET PROPULSION LABORATORY (*top*); PAL HERMANSEN *Stone* (*bottom*)


THERE'S A SHORTCUT TO DISCOVERING
THE LATEST BREAKTHROUGHS IN
SCIENCE & TECHNOLOGY...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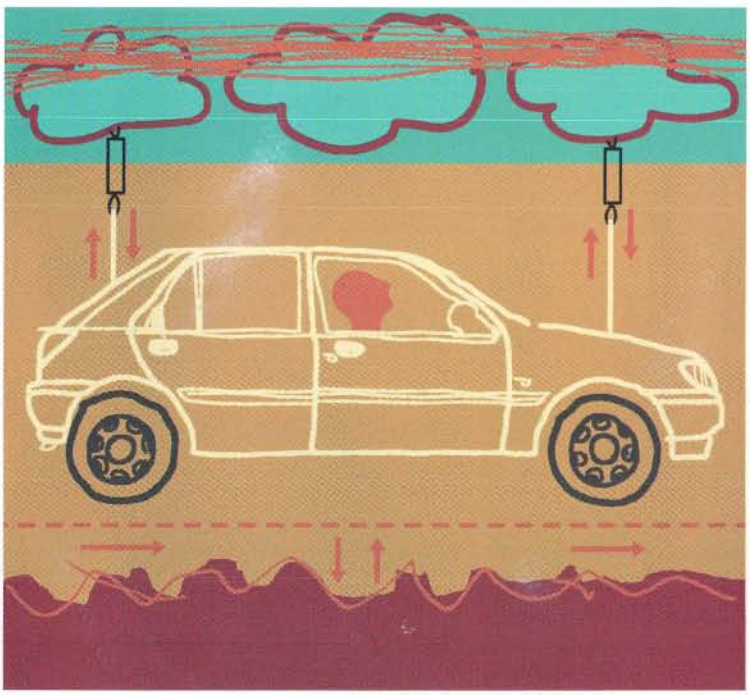
Project Skyhook

A "smart" material that transforms from a liquid to solid state on cue is beginning to show up in prosthetics, automobiles and other applications By GARY STIX

In the early 1970s Dean C. Karnopp of the University of California at Davis and Michael J. Crosby of Lord Corporation wanted to create the perfect ride for a car, truck or bus. They imagined the ultimate shock absorbers: attached to the car body over each wheel on one end but extending up to imaginary hooks in the sky that moved along with the vehicle. As the wheels bounced on hitting a bump, the sky shocks would thrust downward to keep the body in a level position, making a dirt road feel like a plush carpet.

That, in fact, is what a conventional shock absorber is supposed to do. But a shock from the local garage, although it provides some cushioning, can actually transmit, not absorb, energy when you go over a big bump too fast. A down-to-earth version of a skyhook would have to turn off the shock-absorbing qualities of the device gradually as the tire moved up after hitting a bump—and then turn the shock on bit by bit as the tire dropped into a pothole. The difference between a passive and an active device is the difference between stepping directly into a fist in the face or rolling with a punch.



JOHN McFAUL

The practical implementation of Karnopp and Crosby's work was an electromechanical shock absorber that adjusted its resistance based on inputs from a sensor that detected vibrations from the road, a scheme that proved too cumbersome and expensive for a cost-sensitive automobile industry during the 1970s. But the idea remained appealing to Lord, a company that has specialized in high-technology adhesives and damping devices.

The goal of building active suspensions gained momentum during the 1980s, when the company started exploring unusual materials called electrorheological (ER) fluids, which solidify progressively as the strength of an electric field increases. A shock absorber filled with ER fluid could thicken gradually to provide just the necessary damping motions required.

But the properties of the fluids increasingly confounded the Lord research staff. High voltages were required to solidify ER fluids, and the electrical properties changed quickly when exposed to even minimal levels of contaminants and moisture. "You could make things work in the lab," says J. David Carlson, an engineering fellow at Lord. "The problem was that if you tried to take them out of the lab, life got real tough."

These inadequacies led directly to an obscure cousin of ER fluids that had been discovered in the late 1940s by Jacob Rabinow of what was then the National Bureau of Standards. (A prolific inventor, he also devised the magnetic-disk memory.) The principle of magnetorheological (MR) fluids is as simple as a high school science experiment: Put iron filings in oil. Apply a magnetic field, and the particles align in rows like little soldiers. At the same time, the fluid changes to a solid in a matter of milliseconds.

Contemplating MR fluids, Carlson did some quick

calculations, realizing immediately that he might have found a way around the intractability of ER materials. "With MR, you can make a fluid with a field 20 times stronger than an ER fluid, and you don't have 5,000 volts flitting around," he says. "You can make an electromagnet for an MR fluid survive on 12 volts, and that's for free in a car." Within six weeks, the company switched its entire research effort over to MR fluids. "We had a fully functional MR fluid that worked better than any ER damper."

Lord's first application was an MR device to adjust the resistance levels in Nautilus home-exercise machines. The low power consumption seemed an attractive design feature—and an exercise bike was a less demanding application than an automobile shock absorber. Intended for the home, however, the exercise machines soon made their way into health clubs. After a few months of heavy usage there, the machines froze in one position—the liquid had heated up and turned into a viscous goo.

The Lord team was uncertain whether it had only to reengineer the oil in which the particles were suspended or whether it had encountered a fundamental material property that would make MR unusable in any application. "This is the dirtiest oil in the world," Carlson notes, "and if you talk to people in hydraulics they'll tell you that you have to keep things clean." For two years, Lord made various adjustments, changing the composition of the oil, the iron particles, additives and the metals that made up the housing and pistons. Meanwhile tensions mounted between one group doing the basic developmental work on the MR fluids and another trying to use those fluids to fashion new products. Ultimately, the applications group, which worked surreptitiously on making its own fluids, solved the problem through trial and error with different formulations, undermining the more deliberate approach of the fluid-development researchers. "We were trying to do rigorous science, and over here was this Edisonian approach," says Lynn Yanyo, manager of sales and marketing in the materials division who headed the fluid-development team at the time. Management quelled the animosities between the two groups by merging them in 1997.

Two subsequent products—a shock absorber for truck seats and a device that allows a broader range of movement in a prosthetic knee—had more success than the exercise application did. Though not big revenue producers, they piqued the interest of automakers, never eager to try untested new technologies. "Everybody wants to be second," Yanyo says of the attitude toward untested "smart" materials. In considering the devices for automotive suspensions, the carmakers worried about weight: 50 gallons of MR fluid weighs half a ton. But the Lord team could by then point to how little of the fluid is used in prosthetic legs, where weight considerations are crucial.

General Motors announced last fall that it will use shock absorbers from Delphi that incorporate Lord's MR fluid to build an active suspension, called MagneRide, in its 2003 Cadillacs. Lord has thus far developed 14 applications for the product, including dampers for the rotary drum of a washing machine as well as devices to protect buildings and bridges from the shaking of earthquakes. It might also be used one day to supply force feedback in virtual reality.

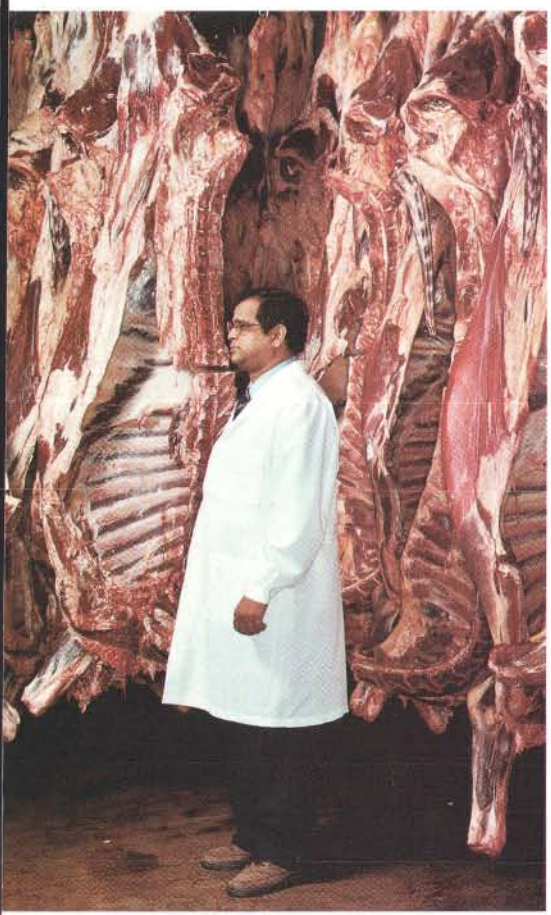
Lord researchers had to engineer a product using "the dirtiest oil in the world."

Researchers still constantly fend off inquiries on the company's Web site from people who suggest vests that would harden when a bullet hits them or prosthetics for men that would substitute for Viagra. But the jury is still out for MR fluids. "If it costs as much as a conventional technology that gives you 90 percent of the benefit, then it may not be widely adopted," says John Ginder, staff technical specialist at the Ford Research Laboratory in Dearborn, Mich. He acknowledges that there might be applications—some types of clutches, for instance—in which the technology would provide significant performance advantages. Despite lingering reservations, the imminent commercialization of MR fluids marks a milestone in the materials sciences. Until now, smart materials, which take advantage of changes in their material properties, have always amounted to laboratory playthings. Lord is one of the first to make a product that not only alters its state on cue but can also be packaged with an invoice. SA

Antimicrobe Marinade

A protein from cow's milk may become a weapon in the fight against the killer hamburger By GARY STIX

Before 1982 the Centers for Disease Control and Prevention had no record of the disease-causing properties of a strain of *Escherichia coli* bacteria that today infects 73,000 people a year. Since its emergence, researchers in government, academia and the food industry have labored to find ways to counter *E. coli* 0157:H7, while continuing their struggle against a host of other pathogens that contaminate the food supply.



A. S. NAIDU'S patent protects meat against microbes.

The use of radiation to kill the bacteria directly is still controversial. A wholly different approach would stop the bacteria from tainting meat in the first place. A. S. Naidu, a medical microbiologist who heads the Center for Antimicrobial Research at California State Polytechnic University, received a patent (U.S.: 6,172,040) for a method of applying to meat a natural protein from cow's milk, the same compound that is credited with protecting infants from bacterial infections while their immune systems develop. Lactoferrin prevents the attachment on the meat surface of more than 30 types of bacteria, including *Salmonella* and *Campylobacter*, in addition to the much feared strain of *E. coli*. It can be used for other applications as well. "This is a microbial blocking agent that detaches a variety of microorganisms from biological surfaces," Naidu says. "[The surface] could be meat, but [the agent] also could be used for removing bacteria from a tooth or from acne on skin."

In meat, the protein binds to tissue-matrix proteins, such as collagen, removing any microbes from those surfaces and preventing new ones from attaching. Lactoferrin must first be immobilized on a sugar substrate to become activated but then remains effective for weeks, even when meat is ground or processed in other ways, Naidu says.

A water-based spray or other methods can apply lactoferrin to meat during slaughter or meat grinding. The compound, moreover, does not affect taste or appearance. Farmland National Beef Packing Company in Kansas City, Mo., has licensed from Naidu the commercial development rights for the technology, which awaits approval from the U.S. Food and Drug Administration.

Whereas Naidu's technology provides a protective coating, two patents from the University of Georgia take preventive measures by going inside the beast. Richard E. Wooley and Emmett B. Shotts, Jr., received one patent (U.S.: 6,083,500) and Michael P. Doyle another (U.S.: 5,965,128) for controlling *E. coli* by getting livestock to ingest strains of harmless bacteria that inhibit the bad actors in an animal's gut. In the Wooley and Shotts patent, a harmless strain of *E. coli* or other bacteria is genetically engineered to produce an antibacterial protein in an animal against *E. coli* or other disease-causing bacteria. In Doyle's patent, strains of beneficial *E. coli* are cultured to stop growth of *E. coli* 0157:H7 in the intestinal tract. Killing the bacteria or inhibiting growth prevents the pathogen from being excreted in fecal matter, a major source of meat contamination. Animals can ingest the beneficial bacteria in feed or drinking water. Thus, a good bug can foil a bad one.

Please let us know about interesting or unusual patents. Send suggestions to: patents@sciam.com

CATHERINE LEDNER

The Erotic-Fierce People

The latest skirmish in the "anthropology wars" reveals a fundamental flaw in how science is understood and communicated By MICHAEL SHERMER

Another battle has broken out in the century-long "anthropology wars" over the truth about human nature. Journalist Patrick Tierney, in his book dramatically entitled *Darkness in El Dorado: How Scientists and Journalists Devastated the Amazon*, purportedly reveals "the hypocrisy, distortions, and humanitarian crimes committed in the name of research, and reveals how the Yanomami's internecine warfare was, in fact, triggered by the repeated visits of outsiders who went looking for a 'fierce' people whose existence lay primarily in the imagination of the West."

Tierney's bête noir is Napoleon Chagnon, whose ethnography *Yanomamö: The Fierce People* is the best-selling anthropological book of all time. Tierney spares no ink in painting him as an anthropologist who sees in the Yanomamö a reflection of himself. Chagnon's sociobiological theories of the most violent and aggressive males winning the most copulations and thus passing on their genes for "fierceness," Tierney says, is merely a window into Chagnon's own libidinous impulses.

Humans are not easily pigeonholed into clear-cut categories.

Are the Yanomamö the "fierce people"? Or are they the "erotic people," as described by French anthropologist Jacques Lizot, another of Tierney's targets? The problem lies in the phrasing of the question. Humans are not easily pigeonholed into such clear-cut categories. The nature and intensity of our behavior depend on a host of biological, social and historical variables. Chagnon understands this. Tierney does not. Thus, *Darkness in El Dorado* fails not just because he didn't get the story straight (there are countless factual errors and distortions in the book) but because the book is predicated on a misunderstanding of how science works and of the difference between anecdotes (on which Tierney's book is based) and statistical trends (on which Chagnon's book depends).

To be sure, Tierney is a good storyteller, but this is what makes his attack on science so invidious. Because humans are storytelling animals, we are more readily convinced by dramatic anecdotes than by dry data. Many of his stories enraged me ... until I checked Tierney's sources myself.

For example, Tierney accuses Chagnon of using the Yanomamö to support a sociobiological model of an aggressive human nature. Yet the primary sources in question show that Chagnon's deductions from the data are not so crude. Even on the final page of his chapter on Yanomamö warfare, Chagnon inquires about "the likelihood that people, throughout history, have based their political relationships with other groups on predatory versus religious or altruistic strategies and the cost-benefit dimensions of what the response should be if they do one or the other." He concludes: "We have the evolved capacity to adopt either strategy." These are hardly the words of a hidebound ideologue bent on indicting the human species.

The fourth edition of Chagnon's classic carries no subtitle. Had he determined that the Yanomamö were not "the fierce people" after all? No. He realized that too often people "might get the impression that being 'fierce' is incompatible with having other sentiments or personal characteristics like compassion, fairness, valor, etc." As his opening chapter notes, the Yanomamö "are simultaneously peacemakers and valiant warriors." Like all people, the Yanomamö have a deep repertoire of responses.

My conclusion is that Chagnon's view of the Yanomamö is basically supported by the evidence. His data and interpretations are corroborated by many other anthropologists. Even at their "fiercest," however, the Yanomamö are not so different from many other peoples around the globe. Yanomamö violence is certainly no more extreme than that of our Paleolithic ancestors, who appear to have brutally butchered one another with abandon. If recorded history is any measure of "fierceness," the Yanomamö have got nothing on Western "civilization."

Homo sapiens are the erotic-fierce people, making love and war too often for our own good. Fortunately, we now have the scientific tools to illuminate our true natures and to help us navigate the treacherous shoals of surviving the transition from a state society to whatever comes next.

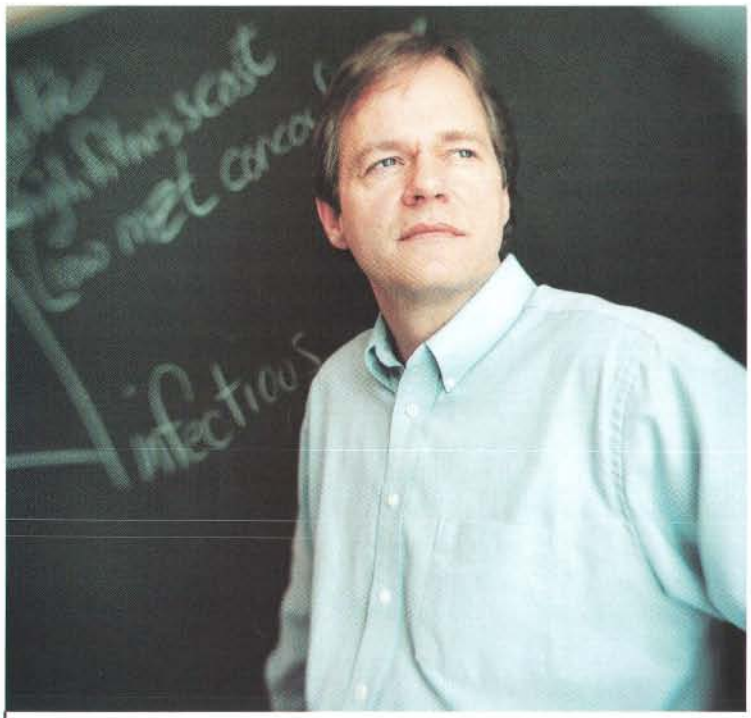
Michael Shermer is editor in chief of Skeptic *magazine.*

BRAD HINES

A Host with Infectious Ideas

Paul W. Ewald argues that most cancers, heart disease and other chronic ills stem from infections. If correct, his theory will change the course of medicine By STEVE MIRSKY

AMHERST, MASS.—Newton had a falling apple. Darwin mused on finches. Paul W. Ewald's inspiration was diarrhea. "I wish I had something more romantic," says the Amherst College evolutionary biologist. It gets uglier: Ewald, then a graduate student studying bird behavior, was camped near a Kansas garbage dump. As he waged a three-day battle against his sea of troubles, he contemplated the interactions between a host—himself, in this case—and a pathogen. "There's some organism in there," Ewald remembers thinking during that 1977 experience, "and this diarrhea might be my way of getting rid of the organism—or it might be the organism's way of manipulating my body" to maximize its chances of passage to the next victim by, for example, contaminating the water supply. "If it's a manipulation and you treat it, you're avoiding damage," he notes. "But if it's a defense and you treat it, you sabotage the host."



PAUL W. EWALD: EVOLUTION OF A HOST

- Born in Wilmette, Ill., to physicist father, Arno, and psychologist mother, Sara; wife, Christine Bayer, two children
- Pursued sociobiology but has concentrated on evolutionary medicine; Ph.D. in zoology from University of Washington, 1980
- Publishes with freelance physicist Gregory M. Cochran—source of idea about infectious causation of chronic illness
- Hobby and primary mode of 10-mile commute: bicycling

Host-pathogen relationships have dominated Ewald's thoughts ever since, leading to numerous articles, two books and, depending on whom you talk to, the respect or scorn of scientists and physicians. The admiration comes from those who think he was on to something really big in his earlier publications, which he summed up in his 1994 book *Evolution of Infectious Disease*. "I think that Paul Ewald has been a pioneer in using evolutionary theory to attack hard questions in pathogenesis," comments Stephen Morse, a virologist and epidemiologist at Columbia University. "His work has, for the first time, shown a way to generate testable hypotheses to study such questions as the evolution of virulence—once thought intractable—and infectious causes of chronic diseases." Indeed, the *Atlantic Monthly* referred to Ewald as "the Darwin of the microworld" (to which Ewald responds, "No, Darwin is Darwin of the microworld, too").

Any antipathy is the result of his latest research, outlined in last year's *Plague Time*. The 47-year-old Ewald argued in the book that infection may play a role in cancer, atherosclerosis, Alzheimer's and other chronic conditions ordinarily thought of as inevitable consequences of genetics, lifestyle or aging. "Some of his recent work is controversial," Morse states. "I'd personally prefer to reserve judgment for now on those questions, at least until more data are in." Others are less gracious. One prominent atherosclerosis researcher politely panned Ewald in public but privately referred to

PHOTOGRAPHS BY KATHLEEN DOOHER; SKELETON LOCATED AT PRATT MUSEUM OF NATURAL HISTORY, AMHERST COLLEGE

his ideas using an eight-letter word, the first half of which is "bull."

In an April 1993 *Scientific American* article, Ewald smashed the old, and unfortunately still widely accepted, notion that parasites and their hosts inevitably evolve toward a benign coexistence. The tendency toward benignity is reserved for conditions passed directly from person to person. Someone too sick to mingle with others would indeed be a dead end for the most dangerous infections, but Ewald showed that infectious agents that use intermediate vectors for transmission, such as malaria's mosquitoes and cholera's contaminated water, are free to evolve toward greater destructive power. After all, a mosquito is free to feed on the sickest malaria victims and thus pass on the worst pathogens. Even more provocative was Ewald's exegesis on our potential to drive the evolution of pathogens through judicious public health measures. "The evolutionary hypothesis says that if you can make it so that sick people cannot pass on infections and that only healthy people can, you should favor the evolution of more benign strains," he explains.

EWALD ponders the evolutionary interplay between microbes and large organisms such as ourselves.

Ewald suggests an experiment that could never be ethically done: "Select two countries, one with bad water and one with clean water, and introduce cholera into both." Theory holds that water in which microbes can thrive serves as a vector that lets dangerous virulence continue or worsen. On the other hand, treated water would kill cholera strains relying on diarrhea for transport; only mild strains would survive because their hosts would be healthy enough to transmit the pathogen directly to other people. "Essentially, that's what happened in 1991," Ewald says, referring to a cholera outbreak in Peru that spread through Latin America. He and his students analyzed cholera from Peru and Guatemala, which has unsafe water, and from Chile, whose water is trustworthy. They found that over the 1990s Chile's cholera did indeed become less virulent, whereas highly toxic strains persisted in the other countries.

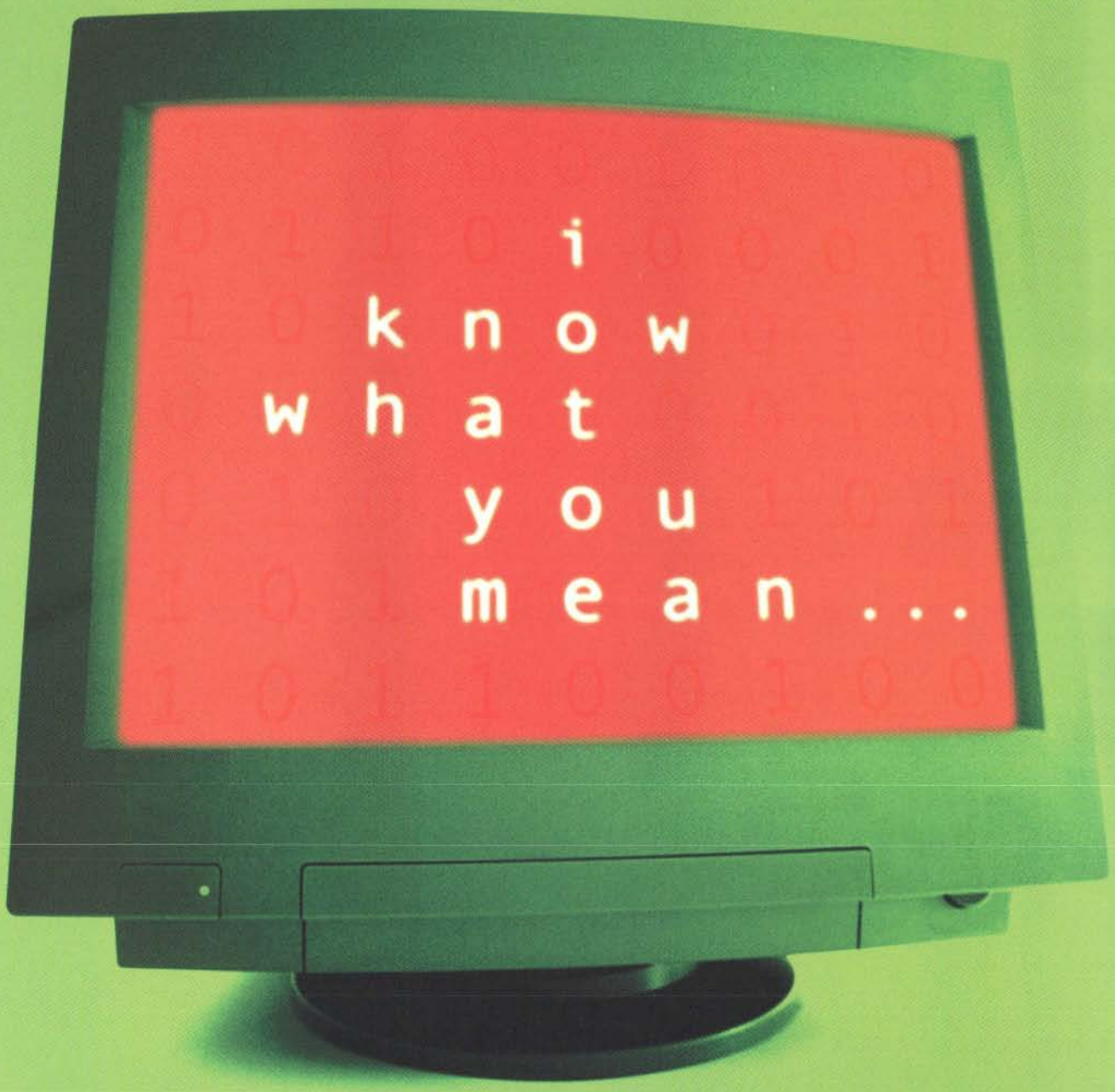
This concept should motivate public health officials to do things they should already be doing anyway, such as providing safe water and mosquito-proof housing. Although these ideas have yet to permeate medical school curricula fully, they seem beyond reproach theoretically. When Ewald wanders into the fields of chronic disease, however, he steps into some eight-letter castigation. Given evolutionary principles and the available evidence, he argues in *Plague Time,* infectious agents should be considered as at least part of the etiology of apparently noninfectious conditions. Of course, the connection between *Helicobactor pylori* and peptic ulcers is now taken for granted, although medical texts of 20 years ago were mute on the subject. Associations between infections and some cancers—hepatitis virus with liver cancer, papillomavirus with cervical cancer—have become accepted in only the past few decades. Ewald thinks that more cancers, perhaps the majority, as well as numerous other common, widespread and ancient chronic diseases, will eventually become linked with various infections: for atherosclerosis and Alzheimer's disease, he points to studies showing associations with *Chlamydia pneumoniae*. He even holds that schizophrenia may be related to infection with the protozoan *Toxoplasma gondii*.

"People have put much more emphasis on genetic causation and noninfectious environmental causation," Ewald says. "And when they find evidence that those kinds of causation are occurring, then they make this fundamental error in science: throwing out a hypothesis [infection] just because you have evidence that other hypotheses are probably at least partly right." Disease instead may result from a subtle interplay between a gene's product and an infectious agent.

Arguably, natural selection should have gotten rid of most of the solely genetic diseases long ago. (Genetic conditions such as sickle-cell disease get an evolutionary pass, however: one copy of the gene protects against disease—malaria, in the case of sickle cell—so the potentially destructive gene will survive in a population.) The standard argument is that genes that cause illness after the prime reproductive years don't get selected against. Ewald counters by arguing that the elderly—and he believes that there were always people who would be considered old by today's standards, even at times when life was supposed to be "nasty, brutish and short"—were important sources of information and caregiving, and evolution does indeed try to keep them around.

To find possible infectious relationships to seemingly noninfectious diseases, Ewald suggests the creation of a program akin to that used to monitor adverse reactions to vaccines: what he calls the Effects of Antimicrobials Reporting System, or EARS. Physicians worldwide may be sitting on a gold mine of data, in the form of anecdotes about remissions that accompany antibiotic treatment for a concurrent condition. "If you accumulate the shared experiences, real cause and effect should pop out," he says. "Then we'd know if this was something we should do a controlled study on."

Ewald believes that the associations between chronic diseases and infections will be slowly accepted, perhaps in a few decades. Should his viewpoint prevail some distant day, he may repeat the words his physicist father once spoke. The elder Ewald, recovering from a heart attack when Paul's 1993 article appeared in this, his favorite publication, said, "Well, this was worth living for." SA


i
know
what
you
mean...

THE SEMANTIC WEB

A new form of Web content that is meaningful to computers will unleash a revolution of new possibilities

by
TIM BERNERS-LEE,
JAMES HENDLER and
ORA LASSILA

PHOTOILLUSTRATIONS BY MIGUEL SALMERON

*The entertainment system was belting out the Beatles' "We Can Work It Out" when the phone rang. When Pete answered, his phone turned the sound down by sending a message to all the other **local** devices that had a **volume control**. His sister, Lucy, was on the line from the doctor's office: "Mom needs to see a specialist and then has to have*

a series of physical therapy sessions. Biweekly or something. I'm going to have my agent set up the appointments." Pete immediately agreed to share the chauffeuring.

At the doctor's office, Lucy instructed her Semantic Web agent through her handheld Web browser. The agent promptly retrieved information about Mom's ***prescribed treatment*** from the doctor's agent, looked up several lists of ***providers,*** and checked for the ones ***in-plan*** for Mom's insurance within a ***20-mile radius*** of her ***home*** and with a ***rating*** of ***excellent*** or ***very good*** on trusted rating services. It then began trying to find a match between available ***appointment times*** (supplied by the agents of individual providers through their Web sites) and Pete's and Lucy's busy schedules. (The emphasized keywords indicate terms whose semantics, or meaning, were defined for the agent through the Semantic Web.)

In a few minutes the agent presented them with a plan. Pete didn't like it—University Hospital was all the way across town from Mom's place, and he'd be driving back in the middle of rush hour. He set his own agent to redo the search with stricter preferences about ***location*** and ***time***. Lucy's agent, having ***complete trust*** in Pete's agent in the context of the present task, automatically assisted by supplying access certificates and shortcuts to the data it had already sorted through.

Almost instantly the new plan was presented: a much closer clinic and earlier times—but there were two warning notes. First, Pete would have to reschedule a couple of his ***less important*** appointments. He checked what they were—not a problem. The other was something about the insurance company's list failing to include this provider under ***physical therapists:*** "Service type and insurance plan status securely verified by other means," the agent reassured him. "(Details?)"

Lucy registered her assent at about the same moment Pete was muttering, "Spare me the details," and it was all set. (Of course, Pete couldn't resist the details and later that night had his agent explain how it had found that provider even though it wasn't on the proper list.)

Overview / Semantic Web

- To date, the World Wide Web has developed most rapidly as a medium of documents for people rather than of information that can be manipulated automatically. By augmenting Web pages with data targeted at computers and by adding documents solely for computers, we will transform the Web into the Semantic Web.
- Computers will find the meaning of semantic data by following hyperlinks to definitions of key terms and rules for reasoning about them logically. The resulting infrastructure will spur the development of automated Web services such as highly functional agents.
- Ordinary users will compose Semantic Web pages and add new definitions and rules using off-the-shelf software that will assist with semantic markup.

Expressing Meaning

PETE AND LUCY could use their agents to carry out all these tasks thanks not to the World Wide Web of today but rather the Semantic Web that it will evolve into tomorrow. Most of the Web's content today is designed for humans to read, not for computer programs to manipulate meaningfully. Computers can adeptly parse Web pages for layout and routine processing—here a header, there a link to another page—but in general, computers have no reliable way to process the semantics: this is the home page of the Hartman and Strauss Physio Clinic, this link goes to Dr. Hartman's curriculum vitae.

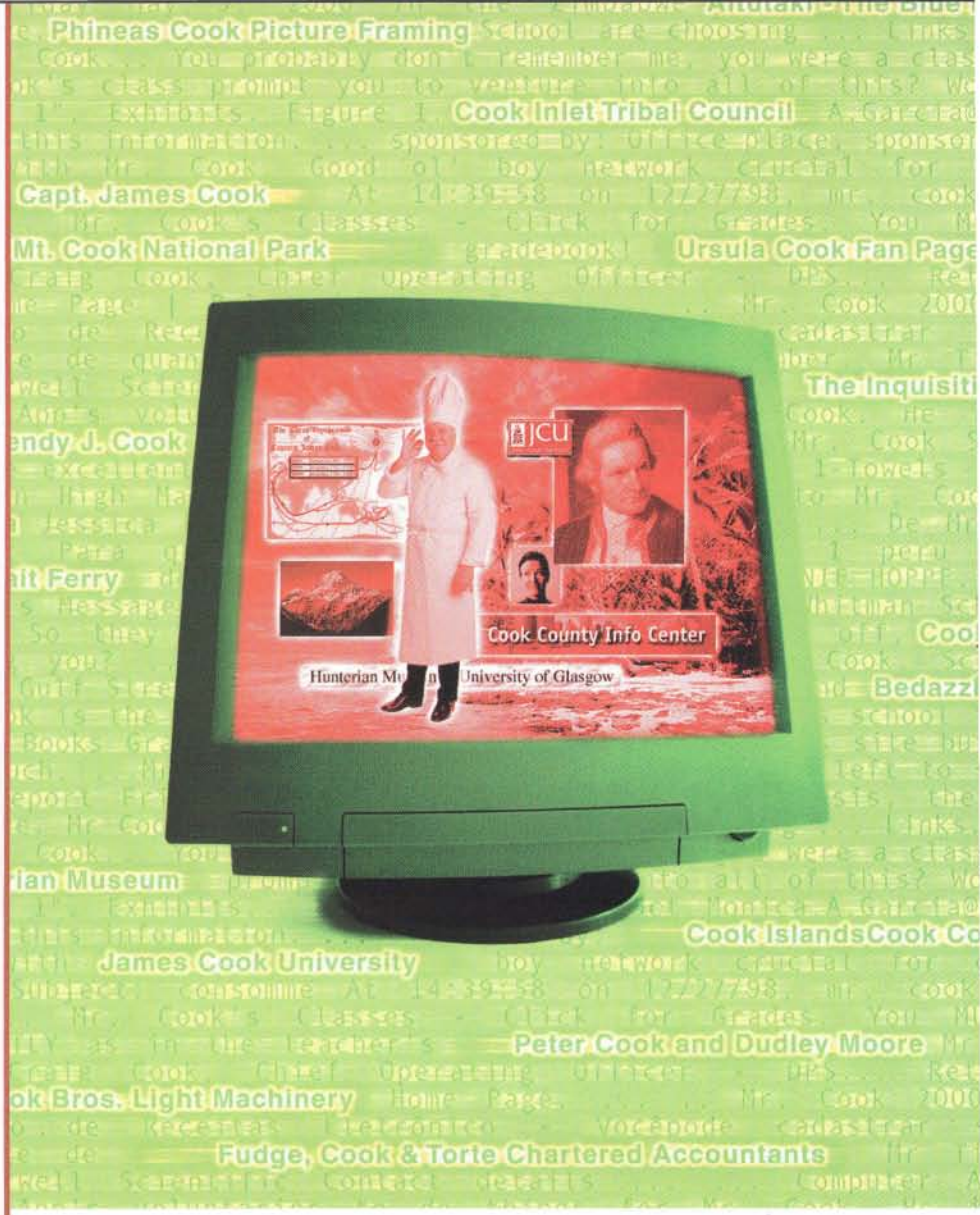
The Semantic Web will bring structure to the meaningful content of Web pages, creating an environment where software agents roaming from page to page can readily carry out sophisticated tasks for users. Such an agent coming to the clinic's Web page will know not just that the page has keywords such as "treatment, medicine, physical, therapy"

(as might be encoded today) but also that Dr. Hartman ***works*** at this ***clinic*** on ***Mondays, Wednesdays*** and ***Fridays*** and that the script takes a ***date range*** in ***yyyy-mm-dd format*** and returns ***appointment times***. And it will "know" all this without needing artificial intelligence on the scale of *2001*'s Hal or *Star Wars*'s C-3PO. Instead these semantics were encoded into the Web page when the clinic's office manager (who never took Comp Sci 101) massaged it into shape using off-the-shelf software for writing Semantic Web pages along with resources listed on the Physical Therapy Association's site.

The Semantic Web is not a separate Web but an extension of the current one, in which information is given well-defined meaning, better enabling computers and people to work in cooperation. The first steps in weaving the Semantic Web into the structure of the existing Web are already under way. In the near future, these developments will usher in significant new functionality as machines become much better able to process and "understand" the data that they merely display at present.

The essential property of the World Wide Web is its universality. The power of a hypertext link is that "anything can link to anything." Web technology, therefore, must not discriminate between the scribbled draft and the polished performance, between commercial and academic information, or among cultures, languages, media and so on. Information varies along many axes. One of these is the difference between information produced primarily for human consumption and that produced mainly for machines. At one end of the scale we have everything from the five-second TV commercial to poetry. At the other end we have databases, programs and sensor output. To date, the Web has developed most rapidly as a medium of documents for people rather than for data and information that can be processed automatically. The Semantic Web aims to make up for this.

Like the Internet, the Semantic Web will be as decentralized as possible. Such Web-like systems generate a lot of excitement at every level, from major corporation to individual user, and provide benefits that are hard or impossible to predict in advance. Decentralization requires compromises: the Web had to throw away the ideal of total consistency of all of its interconnections, ushering in the infamous message "Error 404: Not Found" but allowing unchecked exponential growth.



WEB SEARCHES TODAY typically turn up innumerable completely irrelevant "hits," requiring much manual filtering by the user. If you search using the keyword "cook," for example, the computer has no way of knowing whether you are looking for a chef, information about how to cook something, or simply a place, person, business or some other entity with "cook" in its name. The problem is that the word "cook" has no meaning, or semantic content, to the computer.

Knowledge Representation

FOR THE SEMANTIC WEB to function, computers must have access to structured collections of information and sets of inference rules that they can use to conduct automated reasoning. Artificial-intelligence researchers have studied such systems since long before the Web was developed. Knowledge representation, as this technology is often called, is currently in a state comparable to that of hypertext before the advent of the Web: it is clearly a good idea, and some very nice demonstrations exist, but it has not yet changed the world. It contains the seeds of important applications, but to realize its full potential it must be linked into a single global system.

Traditional knowledge-representation systems typically have been centralized, requiring everyone to share exactly the same definition of common concepts

Glossary

HTML: Hypertext Markup Language. The language used to encode formatting, links and other features on Web pages. Uses standardized "tags" such as <H1> and <BODY> whose meaning and interpretation is set universally by the World Wide Web Consortium.

XML: eXtensible Markup Language. A markup language like HTML that lets individuals define and use their own tags. XML has no built-in mechanism to convey the meaning of the user's new tags to other users.

RESOURCE: Web jargon for any entity. Includes Web pages, parts of a Web page, devices, people and more.

URL: Uniform Resource Locator. The familiar codes (such as http://www.sciam.com/index.html) that are used in hyperlinks.

URI: Universal Resource Identifier. URLs are the most familiar type of URI. A URI defines or specifies an entity, not necessarily by naming its location on the Web.

RDF: Resource Description Framework. A scheme for defining information on the Web. RDF provides the technology for expressing the meaning of terms and concepts in a form that computers can readily process. RDF can use XML for its syntax and URIs to specify entities, concepts, properties and relations.

ONTOLOGIES: Collections of statements written in a language such as RDF that define the relations between concepts and specify logical rules for reasoning about them. Computers will "understand" the meaning of semantic data on a Web page by following links to specified ontologies.

AGENT: A piece of software that runs without direct human control or constant supervision to accomplish goals provided by a user. Agents typically collect, filter and process information found on the Web, sometimes with the help of other agents.

SERVICE DISCOVERY: The process of locating an agent or automated Web-based service that will perform a required function. Semantics will enable agents to describe to one another precisely what function they carry out and what input data are needed.

such as "parent" or "vehicle." But central control is stifling, and increasing the size and scope of such a system rapidly becomes unmanageable.

Moreover, these systems usually carefully limit the questions that can be asked so that the computer can answer reliably—or answer at all. The problem is reminiscent of Gödel's theorem from mathematics: any system that is complex enough to be useful also encompasses unanswerable questions, much like sophisticated versions of the basic paradox "This sentence is false." To avoid such problems, traditional knowledge-representation systems generally each had their own narrow and idiosyncratic set of rules for making inferences about their data. For example, a genealogy system, acting on a database of family trees, might include the rule "a wife of an uncle is an aunt." Even if the data could be transferred from one system to another, the rules, existing in a completely different form, usually could not.

Semantic Web researchers, in contrast, accept that paradoxes and unanswerable questions are a price that must be paid to achieve versatility. We make the language for the rules as expressive as needed to allow the Web to reason as widely as desired. This philosophy is similar to that of the conventional Web: early in the Web's development, detractors pointed out that it could never be a well-organized library; without a central database and tree structure, one would never be sure of finding everything. They were right. But the expressive power of the system made vast amounts of information available, and search engines (which would have seemed quite impractical a decade ago) now produce remarkably complete indices of a lot of the material out there.

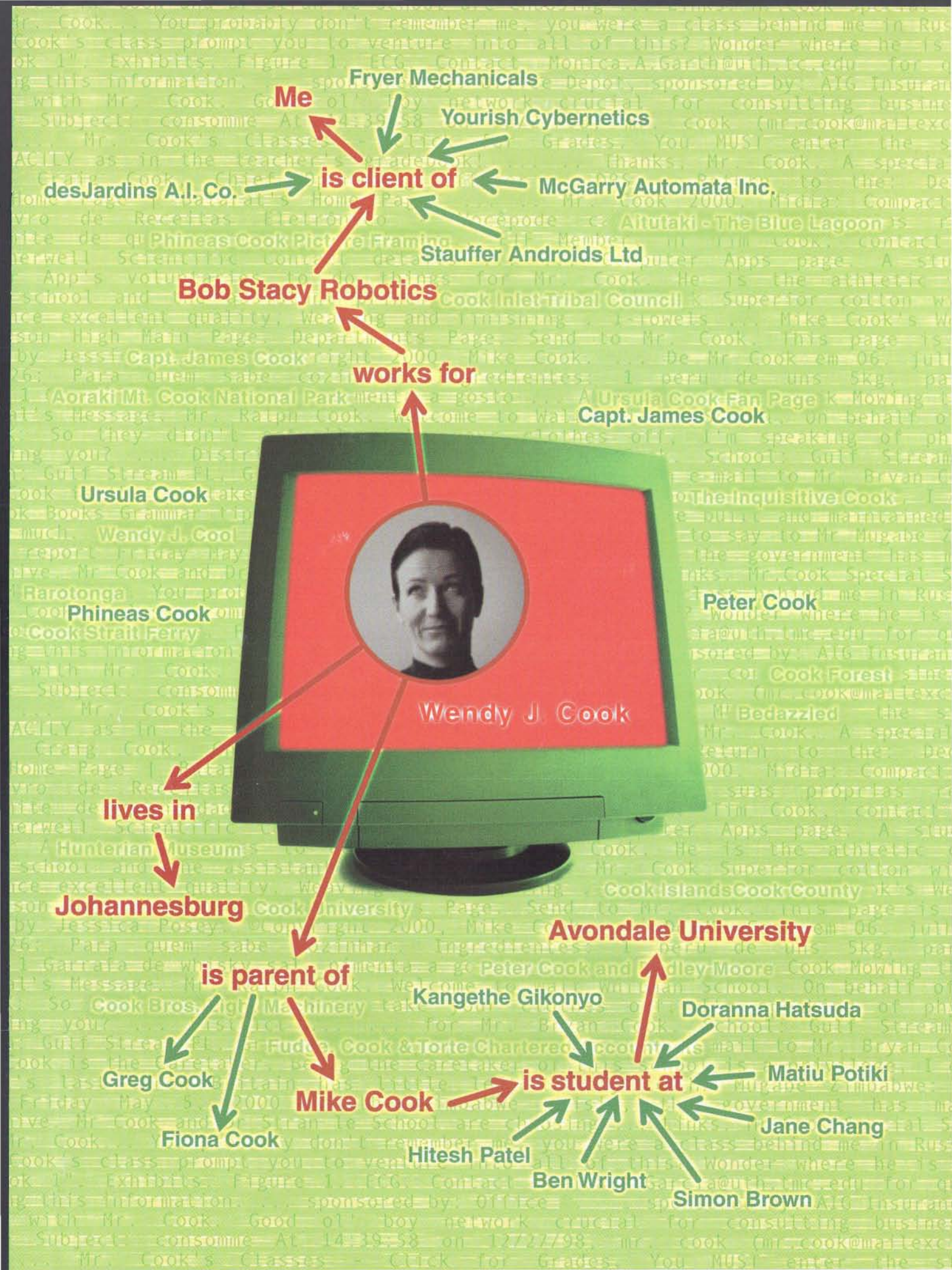
The challenge of the Semantic Web, therefore, is to provide a language that expresses both data and rules for reasoning about the data and that allows rules from any existing knowledge-representation system to be exported onto the Web.

Adding logic to the Web—the means to use rules to make inferences, choose courses of action and answer questions—is the task before the Semantic Web community at the moment. A mixture of mathematical and engineering decisions complicate this task. The logic must be powerful enough to describe complex properties of objects but not so powerful that agents can be tricked by being asked to consider a paradox. Fortunately, a large majority of the information we want to express is along the lines of "a hex-head bolt is a type of machine bolt," which is readily written in existing languages with a little extra vocabulary.

Two important technologies for developing the Semantic Web are already in place: eXtensible Markup Language (XML) and the Resource Description Framework (RDF). XML lets everyone create their own tags—hidden labels such as <zip code> or <alma mater> that annotate Web pages or sections of text on a page. Scripts, or programs, can make use of these tags in sophisticated ways, but the script writer has to know what the page writer uses each tag for. In short, XML allows users to add arbitrary structure to their documents but says nothing about what the structures mean [see "XML and the Second-Generation Web," by Jon Bosak and Tim Bray; SCIENTIFIC AMERICAN, May 1999].

Meaning is expressed by RDF, which encodes it in sets of triples, each triple being rather like the subject, verb and object of an elementary sentence. These triples

ELABORATE, PRECISE AUTOMATED SEARCHES will be possible when semantics are widespread on the Web. Here a search program correctly locates a person based on an assortment of partially remembered knowledge: her last name is "Cook," she works for a company on your client list, and she has a son attending your alma mater, Avondale University. The correct combination of that information does not reside on a single Web page, but semantics make it easier for a program to discern the elements on various pages, understand relations such as "Mike Cook is a child of Wendy Cook" and piece them together reliably. More generally, semantics will enable complicated processes and transactions to be carried out automatically.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McGarry Automata Inc.
Stauffer Androids Ltd
Bob Stacy Robotics
works for
Capt. James Cook
Ursula Cook
Peter Cook
Phineas Cook
Wendy J. Cook
lives in
Johannesburg
Avondale University
is parent of
Kangethe Gikonyo
Doranna Hatsuda
Matiu Potiki
Greg Cook
Mike Cook
is student at
Jane Chang
Fiona Cook
Hitesh Patel
Ben Wright
Simon Brown

can be written using XML tags. In RDF, a document makes assertions that particular things (people, Web pages or whatever) have properties (such as "is a sister of," "is the author of") with certain values (another person, another Web page). This structure turns out to be a natural way to describe the vast majority of the data processed by machines. Subject and object are each identified by a Universal Resource Identifier (URI), just as used in a link on a Web page. (URLs, Uniform Resource Locators, are the most common type of URI.) The verbs are also identified by URIs, which enables anyone to define a new concept, a new verb, just by defining a URI for it somewhere on the Web.

Human language thrives when using the same term to mean somewhat different things, but automation does not. Imagine that I hire a clown messenger service to deliver balloons to my customers on their birthdays. Unfortunately, the service transfers the addresses from my database to its database, not knowing that the "addresses" in mine are where bills are sent and that many of them are post office boxes. My hired clowns end up entertaining a number of postal workers—not necessarily a bad thing but certainly not the intended effect. Using a different URI for each specific concept solves that problem. An address that is a mailing address can be distinguished from one that is a street address, and both can be distinguished from an address that is a speech.

The triples of RDF form webs of information about related things. Because RDF uses URIs to encode this information in a document, the URIs ensure that concepts are not just words in a document but are tied to a unique definition that everyone can find on the Web. For example, imagine that we have access to a variety of databases with information about people, including their addresses. If we want to find people living in a specific zip code, we need to know which fields in each database represent names and which represent zip codes. RDF can specify that "(field 5 in database A) (is a field of type) (zip code)," using URIs rather than phrases for each term.

The Semantic Web will enable machines to COMPREHEND semantic documents and data, not human speech and writings.

Ontologies

OF COURSE, THIS IS NOT the end of the story, because two databases may use different identifiers for what is in fact the same concept, such as ***zip code***. A program that wants to compare or combine information across the two databases has to know that these two terms are being used to mean the same thing. Ideally, the program must have a way to discover such common meanings for whatever databases it encounters.

A solution to this problem is provided by the third basic component of the Semantic Web, collections of information called ontologies. In philosophy, an ontology is a theory about the nature of existence, of what types of things exist; ontology as a discipline studies such theories. Artificial-intelligence and Web researchers have co-opted the term for their own jargon, and for them an ontology is a document or file that formally defines the relations among terms. The most typical kind of ontology for the Web has a taxonomy and a set of inference rules.

The taxonomy defines classes of objects and relations among them. For example, an ***address*** may be defined as a type of ***location,*** and ***city codes*** may be defined to apply only to ***locations,*** and so on. Classes, subclasses and relations among entities are a very powerful tool for Web use. We can express a large number of relations among entities by assigning properties to classes and allowing subclasses to inherit such properties. If ***city codes*** must be of type ***city*** and cities generally have Web sites, we can discuss the Web site associated with a ***city code*** even if no database links a city code directly to a Web site.

Inference rules in ontologies supply further power. An ontology may express the rule "If a city code is associated with a state code, and an address uses that city code, then that address has the associated state code." A program could then readily deduce, for instance, that a Cornell University address, being in Ithaca, must be in New York State, which is in the U.S., and therefore should be formatted to U.S. standards. The computer doesn't truly "understand" any of this information, but it can now manipulate the terms much more effectively in ways that are useful and meaningful to the human user.

With ontology pages on the Web, solutions to terminology (and other) problems begin to emerge. The meaning of terms or XML codes used on a Web page can be defined by pointers from the page to an ontology. Of course, the same problems as before now arise if I point to an

THE AUTHORS

TIM BERNERS-LEE, JAMES HENDLER and *ORA LASSILA* are individually and collectively obsessed with the potential of Semantic Web technology. Berners-Lee is director of the World Wide Web Consortium (W3C) and a researcher at the Laboratory for Computer Science at the Massachusetts Institute of Technology. When he invented the Web in 1989, he intended it to carry more semantics than became common practice. Hendler is professor of computer science at the University of Maryland at College Park, where he has been doing research on knowledge representation in a Web context for a number of years. He and his graduate research group developed SHOE, the first Web-based knowledge representation language to demonstrate many of the agent capabilities described in this article. Hendler is also responsible for agent-based computing research at the Defense Advanced Research Projects Agency (DARPA) in Arlington, Va. Lassila is a research fellow at the Nokia Research Center in Boston, chief scientist of Nokia Venture Partners and a member of the W3C Advisory Board. Frustrated with the difficulty of building agents and automating tasks on the Web, he co-authored W3C's RDF specification, which serves as the foundation for many current Semantic Web efforts.

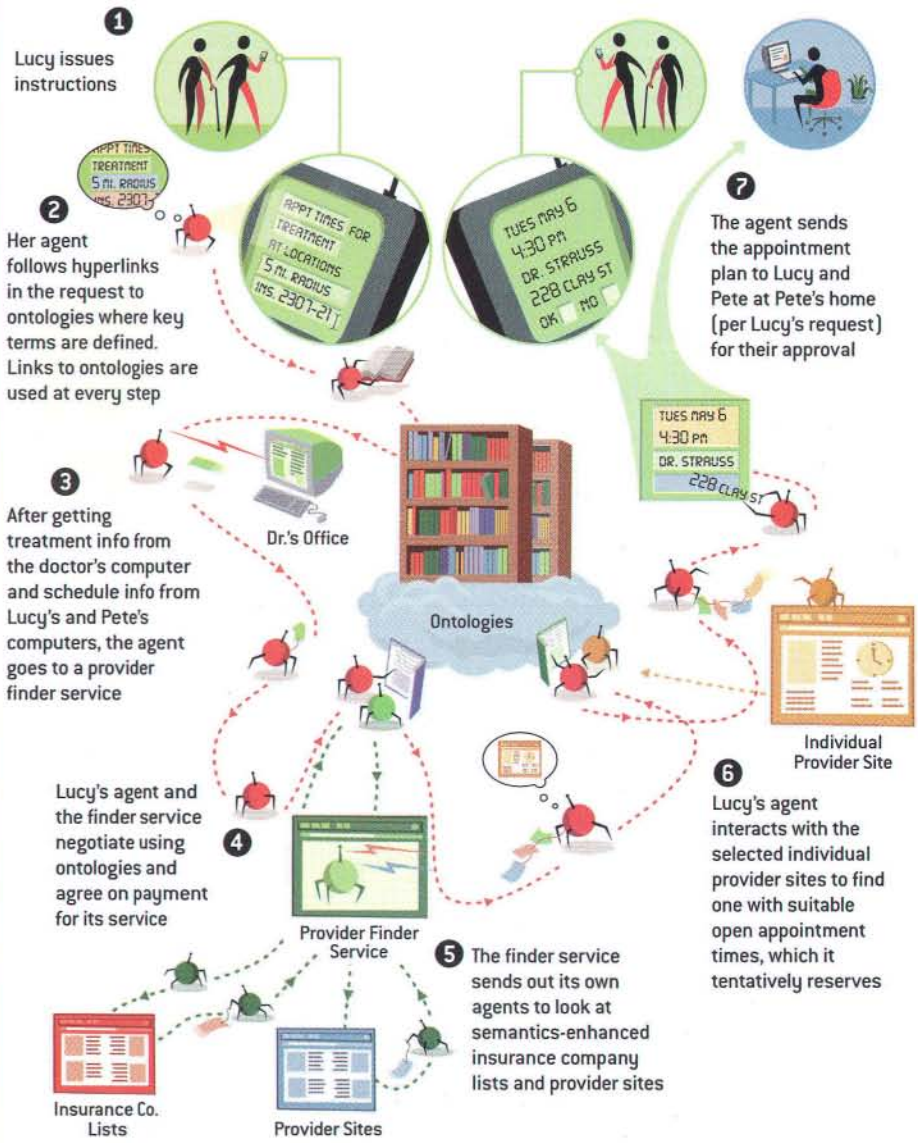
ontology that defines ***addresses*** as containing a ***zip code*** and you point to one that uses ***postal code***. This kind of confusion can be resolved if ontologies (or other Web services) provide equivalence relations: one or both of our ontologies may contain the information that my ***zip code*** is equivalent to your ***postal code***.

Our scheme for sending in the clowns to entertain my customers is partially solved when the two databases point to different definitions of ***address***. The program, using distinct URIs for different concepts of ***address***, will not confuse them and in fact will need to discover that the concepts are related at all. The program could then use a service that takes a list of postal ***addresses*** (defined in the first ontology) and converts it into a list of physical ***addresses*** (the second ontology) by recognizing and removing post office boxes and other unsuitable addresses. The structure and semantics provided by ontologies make it easier for an entrepreneur to provide such a service and can make its use completely transparent.

Ontologies can enhance the functioning of the Web in many ways. They can be used in a simple fashion to improve the accuracy of Web searches—the search program can look for only those pages that refer to a precise concept instead of all the ones using ambiguous keywords. More advanced applications will use ontologies to relate the information on a page to the associated knowledge structures and inference rules. An example of a page marked up for such use is online at http://www.cs.umd.edu/~hendler. If you send your Web browser to that page, you will see the normal Web page entitled "Dr. James A. Hendler." As a human, you can readily find the link to a short biographical note and read there that Hendler received his Ph.D. from Brown University. A computer program trying to find such information, however, would have to be very complex to guess that this information might be in a biography and to understand the English language used there.

For computers, the page is linked to an ontology page that defines information about computer science departments. For instance, professors work at universities and they generally have doctorates. Further markup on the page (not displayed by the typical Web browser) uses the ontology's concepts to specify that Hendler received his Ph.D. from the entity described at the URI http://www.brown.edu/—the Web page for Brown. Computers can also find that Hendler is a member of a particular research project, has a particular e-mail address, and so on. All that information is readily processed by a computer and could be used to answer queries (such as where Dr. Hendler received his degree) that currently would require a human to sift through the content of various pages turned up by a search engine.

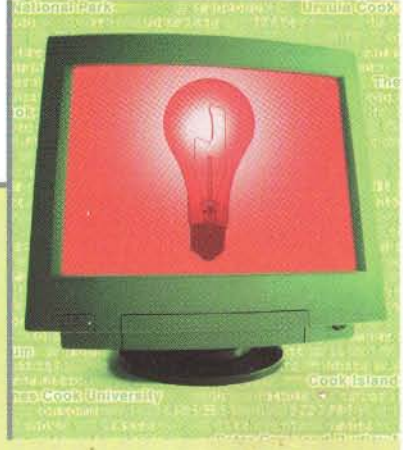
In addition, this markup makes it much easier to develop programs that can tackle complicated questions whose answers do not reside on a single Web page. Suppose you wish to find the Ms. Cook you met at a trade conference last year. You don't remember her first name, but you remember that she worked for one of your clients and that her son was a student at your alma mater. An intelligent search program can sift through all the pages of people whose name is



SOFTWARE AGENTS will be greatly facilitated by semantic content on the Web. In the depicted scenario, Lucy's agent tracks down a physical therapy clinic for her mother that meets a combination of criteria and has open appointment times that mesh with her and her brother Pete's schedules. Ontologies that define the meaning of semantic data play a key role in enabling the agent to understand what is on the Semantic Web, interact with sites and employ other automated services.

XPLANE

What Is the Killer App?



AFTER WE GIVE a presentation about the Semantic Web, we're often asked, "Okay, so what is the killer application of the Semantic Web?" The "killer app" of any technology, of course, is the application that brings a user to investigate the technology and start using it. The transistor radio was a killer app of transistors, and the cell phone is a killer app of wireless technology.

So what do we answer? "The Semantic Web *is* the killer app."

At this point we're likely to be told we're crazy, so we ask a question in turn: "Well, what's the killer app of the World Wide Web?" Now we're being stared at kind of fish-eyed, so we answer ourselves: "The Web is the killer app of the Internet. The Semantic Web is another killer app of that magnitude."

The point here is that the abilities of the Semantic Web are too general to be thought about in terms of solving one key problem or creating one essential gizmo. It will have uses we haven't dreamed of.

Nevertheless, we can foresee some disarming (if not actually killer) apps that will drive initial use. Online catalogs with semantic markup will benefit both buyers and sellers. Electronic commerce transactions will be easier for small businesses to set up securely with greater autonomy. And one final example: you make reservations for an extended trip abroad. The airlines, hotels, soccer stadiums and so on return confirmations with semantic markup. All the schedules load directly into your date book and all the expenses directly into your accounting program, no matter what semantics-enabled software you use. No more laborious cutting and pasting from e-mail. No need for all the businesses to supply the data in half a dozen different formats or to create and impose their own standard format.

"Cook" (sidestepping all the pages relating to cooks, cooking, the Cook Islands and so forth), find the ones that mention working for a company that's on your list of clients and follow links to Web pages of their children to track down if any are in school at the right place.

Agents

THE REAL POWER of the Semantic Web will be realized when people create many programs that collect Web content from diverse sources, process the information and exchange the results with other programs. The effectiveness of such software agents will increase exponentially as more machine-readable Web content and automated services (including other agents) become available. The Semantic Web promotes this synergy: even agents that were not expressly designed to work together can transfer data among themselves when the data come with semantics.

An important facet of agents' functioning will be the exchange of "proofs" written in the Semantic Web's unifying language (the language that expresses logical inferences made using rules and information such as those specified by ontologies). For example, suppose Ms. Cook's contact information has been located by an online service, and to your great surprise it places her in Johannesburg. Naturally, you want to check this, so your computer asks the service for a proof of its answer, which it promptly provides by translating its internal reasoning into the Semantic Web's unifying language. An inference engine in your computer readily verifies that this Ms. Cook indeed matches the one you were seeking, and it can show you the relevant Web pages if you still have doubts. Although they are still far from plumbing the depths of the Semantic Web's potential, some programs can already exchange proofs in this way, using the current preliminary versions of the unifying language.

Another vital feature will be digital signatures, which are encrypted blocks of data that computers and agents can use to verify that the attached information has been provided by a specific trusted source. You want to be quite sure that a statement sent to your accounting program that you owe money to an online retailer is not a forgery generated by the computer-savvy teenager next door. Agents should be skeptical of assertions that they read on the Semantic Web until they have checked the sources of information. (We wish more *people* would learn to do this on the Web as it is!)

Many automated Web-based services already exist without semantics, but other programs such as agents have no way to locate one that will perform a specific function. This process, called service discovery, can happen only when there is a common language to describe a service in a way that lets other agents "understand" both the function offered and how to take advantage of it. Services and agents can advertise their function by, for example, depositing such descriptions in directories analogous to the Yellow Pages.

Some low-level service-discovery schemes are currently available, such as Microsoft's Universal Plug and Play, which focuses on connecting different types of devices, and Sun Microsystems's Jini, which aims to connect services. These initiatives, however, attack the problem at a structural or syntactic level and rely heavily on standardization of a predetermined set of functionality descriptions. Standardization can only go so far, because we can't anticipate all possible future needs.

The Semantic Web, in contrast, is more flexible. The consumer and producer agents can reach a shared understanding by exchanging ontologies, which provide the vocabulary needed for discussion. Agents can even "bootstrap" new reasoning capabilities when they discover new ontologies. Semantics also makes it easier to take advantage of a service that only partially matches a request.

A typical process will involve the creation of a "value chain" in which subassemblies of information are passed from one agent to another, each one "adding value," to construct the final product requested by the end user. Make no mistake:

to create complicated value chains automatically on demand, some agents will exploit artificial-intelligence technologies in addition to the Semantic Web. But the Semantic Web will provide the foundations and the framework to make such technologies more feasible.

Putting all these features together results in the abilities exhibited by Pete's and Lucy's agents in the scenario that opened this article. Their agents would have delegated the task in piecemeal fashion to other services and agents discovered through service advertisements. For example, they could have used a ***trusted*** service to take a list of ***providers*** and determine which of them are ***in-plan*** for a specified ***insurance plan*** and ***course of treatment***. The list of providers would have been supplied by another search service, et cetera. These activities formed chains in which a large amount of data distributed across the Web (and almost worthless in that form) was progressively reduced to the small amount of data of high value to Pete and Lucy—a plan of appointments to fit their schedules and other requirements.

In the next step, the Semantic Web will break out of the virtual realm and extend into our physical world. URIs can point to anything, including physical entities, which means we can use the RDF language to describe devices such as cell phones and TVs. Such devices can advertise their functionality—what they can do and how they are controlled—much like software agents. Being much more flexible than low-level schemes such as Universal Plug and Play, such a semantic approach opens up a world of exciting possibilities.

For instance, what today is called home automation requires careful configuration for appliances to work together. Semantic descriptions of device capabilities and functionality will let us achieve such automation with minimal human intervention. A trivial example occurs when Pete answers his phone and the stereo sound is turned down. Instead of having to program each specific appliance, he could program such a function once and for all to cover every ***local*** device that advertises having a ***volume control***—the TV, the DVD player and even the media players on the laptop that he brought home from work this one evening.

The first concrete steps have already been taken in this area, with work on developing a standard for describing functional capabilities of devices (such as screen sizes) and user preferences. Built on RDF, this standard is called Composite Capability/Preference Profile (CC/PP). Initially it will let cell phones and other nonstandard Web clients describe their characteristics so that Web content can be tailored for them on the fly. Later, when we add the full versatility of languages for handling ontologies and logic, devices could automatically seek out and employ services and other devices for added information or functionality. It is not hard to imagine your Web-enabled microwave oven consulting the frozen-food manufacturer's Web site for optimal cooking parameters.

Properly designed, the Semantic Web can assist the EVOLUTION of human knowledge as a whole.

Evolution of Knowledge

THE SEMANTIC WEB is not "merely" the tool for conducting individual tasks that we have discussed so far. In addition, if properly designed, the Semantic Web can assist the evolution of human knowledge as a whole.

Human endeavor is caught in an eternal tension between the effectiveness of small groups acting independently and the need to mesh with the wider community. A small group can innovate rapidly and efficiently, but this produces a subculture whose concepts are not understood by others. Coordinating actions across a large group, however, is painfully slow and takes an enormous amount of communication. The world works across the spectrum between these extremes, with a tendency to start small—from the personal idea—and move toward a wider understanding over time.

An essential process is the joining together of subcultures when a wider common language is needed. Often two groups independently develop very similar concepts, and describing the relation between them brings great benefits. Like a Finnish-English dictionary, or a weights-and-measures conversion table, the relations allow communication and collaboration even when the commonality of concept has not (yet) led to a commonality of terms.

The Semantic Web, in naming every concept simply by a URI, lets anyone express new concepts that they invent with minimal effort. Its unifying logical language will enable these concepts to be progressively linked into a universal Web. This structure will open up the knowledge and workings of humankind to meaningful analysis by software agents, providing a new class of tools by which we can live, work and learn together. SA

MORE TO EXPLORE

Weaving the Web: The Original Design and Ultimate Destiny of the World Wide Web by Its Inventor. Tim Berners-Lee, with Mark Fischetti. Harper San Francisco, 1999.

An enhanced version of this article is on the Scientific American Web site, with additional material and links.

World Wide Web Consortium (W3C): **www.w3.org/**

W3C Semantic Web Activity: **www.w3.org/2001/sw/**

An introduction to ontologies: **www.SemanticWeb.org/knowmarkup.html**

Simple HTML Ontology Extensions Frequently Asked Questions (SHOE FAQ): **www.cs.umd.edu/projects/plus/SHOE/faq.html**

DARPA Agent Markup Language (DAML) home page: **www.daml.org/**

RIP

THE OLDEST STARS

VAN

HAVE BEEN GROWING YOUNGER

Twinkle

BY BRIAN C. CHABOYER

FROM RED STARS TO RED FACES:
This cluster of stars on the outskirts of our galaxy, known as M80, looks strangely reddish—a sign that it is filled with stars in the twilight of their lives. Until recently, their inferred age contradicted the age of the universe, leaving astronomers to wonder whether cosmological theories had some fatal flaw.

Several years ago the biggest story in cosmology was the "age crisis." Observations of the cosmic expansion rate implied that the universe was 14 billion years old, or younger. Observations of ancient stars found that some were 15 billion years old, or older. The discrepancy grabbed headlines, dominated the agenda at astronomical conferences and inspired all sorts of disturbing analogies about children being older than their mothers. But nowadays people hardly ever talk about an age crisis. What happened?

Science has a rich history of such discrepancies, and they have almost always portended great leaps of understanding. Debates over the age of Earth were crucial to Charles Darwin's formulation of the theory of natural selection. Disagreements over the age of the sun were resolved only by the discovery of nuclear reactions. Albert Einstein's conviction that the universe was eternal and static was upended by Edwin Hubble's observations of receding galaxies.

The recent age crisis, too, was the first shot in a revolution: the realization that the universe is dominated not by ordinary matter or even by dark matter but by a type of dark energy about which cosmologists know almost nothing. The cosmic acceleration imparted by dark energy raises the inferred age of the universe. But that is not the whole story.

Back when the age crisis was such a popular topic of debate, most astronomers blamed the conundrum on cosmology. Either the measurement of the expansion rate was wrong (said the theorists) or the basic cosmological model was wrong (said the observers). Only a minority questioned the stellar ages. The expansion rate had been debated for half a century, often acrimoniously; many of the principals were barely on speaking terms. In contrast, the stellar-age estimate of 15 billion years made by Pierre Demarque of Yale University and others was remarkably robust. From the mid-1960s through the mid-1990s, theoretical models had predicted that the oldest stars were this old, or even older. Astronomers who specialized in this subject were confident of their estimates.

That consensus has turned out to be wrong. Based on results from the Hipparcos satellite as well as new calculations of how stars evolve, astronomers have come to the conclusion that the oldest stars are roughly 13 billion years old. The age crisis is over.

Overview / *The Methuselah Stars*

COMMON SENSE sometimes doesn't go very far in cosmology, but in this case the rule is ironclad: the universe must be older than the oldest stars. Unfortunately, observations used to suggest the opposite. Baffled astronomers tended to blame cosmological theories. As it turns out, the fault lay mostly in stellar astrophysics.

- MANY OF THE OLDEST stars reside in tight swarms known as globular clusters—eerily beautiful objects that are a favorite of amateur astronomers. All of the stars in a given cluster were born at essentially the same time.
- BIG, BRIGHT STARS live fast and die young. The bigger they come, the faster they go. So if you look at a cluster and notice which stars are left, you can calculate how old the whole cluster is.
- THE HIPPARCOS SATELLITE made the breakthrough: it found that globular clusters are farther away than previously thought. Therefore, their stars must be intrinsically brighter and younger. Their age, about 13 billion years, now agrees with the age of the universe, 14 billion years.

Gas Guzzlers

SUPPOSE THE ODOMETER on your car breaks. How can you determine how far you've driven? If you know the size of the gas tank and the gas mileage, it is easy: just divide the fuel supply by the mileage. The same basic technique applies to stars. The size of the tank is the mass of the star, and the mileage is the nuclear burning rate.

For most of their lives, stars are powered by hydrogen fusion. The intense heat deep inside the star melds four hydrogen nuclei (each a single proton) into a single helium nucleus (two protons and two neutrons). Four protons together weigh 0.7 percent more than a single helium nucleus; the missing fraction is converted into energy according to Einstein's famous equation $E = mc^2$. The sun, for example, emits 4×10^{26} watts of light, which means it must be transmuting 600 million tons of hydrogen into 596 million tons of helium a second.

Over a billion years, the sun burns through 1 percent of its

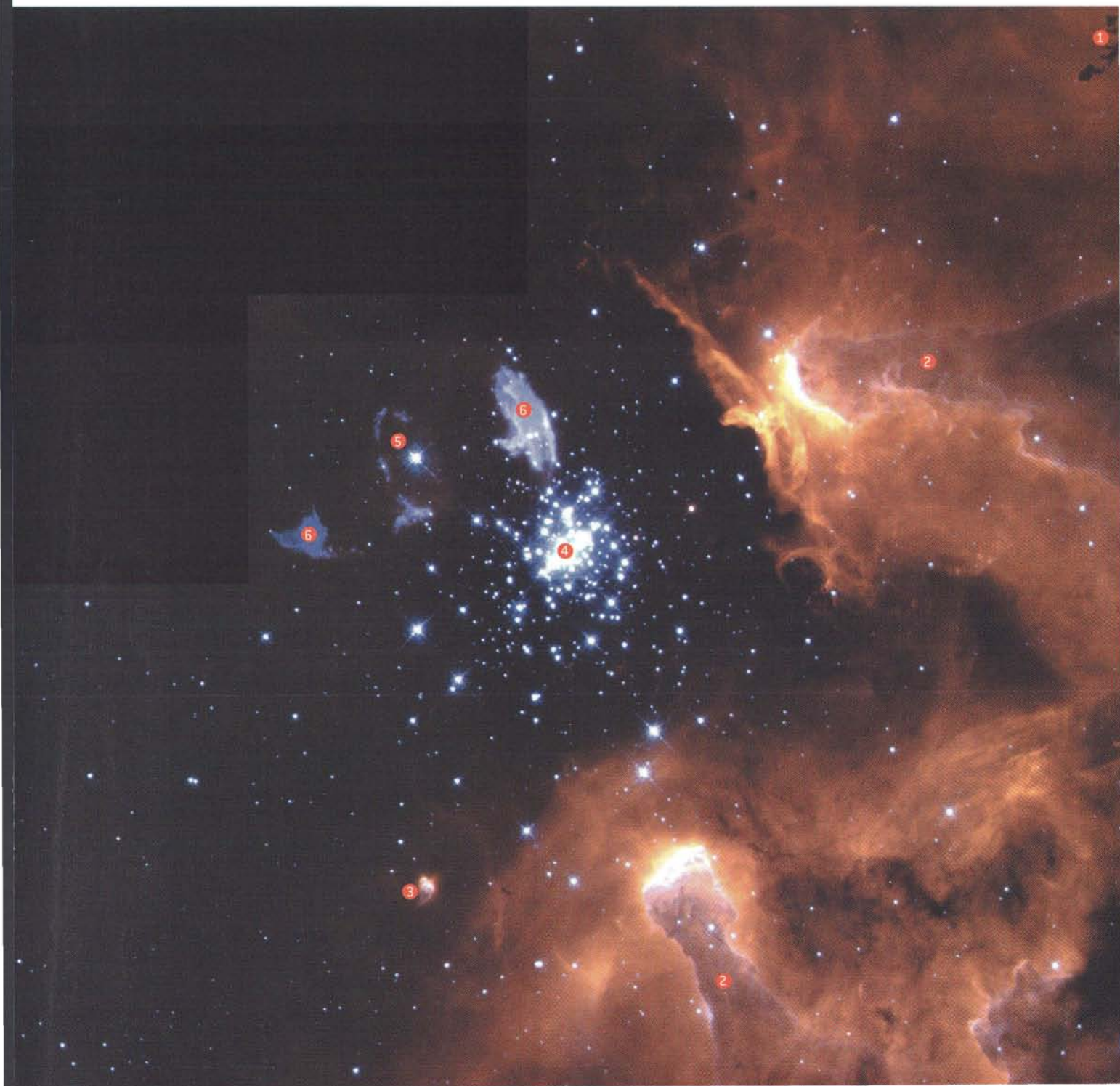
FROM GESTATION THROUGH OLD AGE, stars at various stages of their lives all appear in the nebula NGC 3603: embryonic clouds in the form of Bok globules (*1*) or dense gaseous pillars (*2*), protostars with protoplanetary disks (*3*), a cluster of hot young stars (*4*) and a dying giant star blowing off gas rings (*5*) and blobs (*6*).

HUBBLE HERITAGE TEAM (*preceding page*); WOLFGANG BRANDNER *Jet Propulsion Laboratory/IPAC*, EVA K. GREBEL *University of Washington*, YOU-HUA CHU *University of Illinois at Urbana-Champaign* AND NASA (*opposite page*)

total mass. Because about 10 percent of the sun's mass is usable fuel—this is the portion that reaches the temperatures and densities required for hydrogen fusion—the sun can last for 10 billion years. Over this time, a phase known as the main sequence, it will maintain a roughly constant luminosity and temperature.

Stars heavier than the sun burn their hydrogen at much faster rates—so fast that even though they begin with more fuel, they run out of it sooner. This tendency can be deduced from the physical laws that govern the structure of a star: the law of hydrostatic equilibrium (whereby the force of gravity is balanced by the pressure of the gas), the ideal-gas law (which relates pressure, density and temperature), and the law of radiative heat transport (which determines how steep the temperature gradient must be to ensure that enough energy will

Astronomers were confident of their AGE ESTIMATES.
But that consensus has turned out to be wrong.



leak out of the star). The net result is that the luminosity of a star varies roughly as the fourth power of the mass. The amount of fuel, in contrast, scales simply as the mass. Therefore, the main-sequence lifetime of a star is approximately proportional to the inverse cube of its mass. A star 10 times as massive as the sun is 10,000 times brighter but lasts a thousandth as long—just 10 million years or so. Heavy stars are the sport utility vehicles of the cosmos: impressive looks but atrocious fuel economy.

When a star finally exhausts the hydrogen in its core, it begins to tap gas in the surrounding layers. The star balloons in size and enters its red-giant phase, distinguished by higher luminosity but lower surface temperature. Instead of being white-hot, the star is merely red-hot. In rapid succession, the star resorts to ever more desperate efforts to generate energy, eventually depleting its gas reserves altogether. This evolution is especially easy to see when visual brightness (related to total power output) and color (related to surface temperature) are plotted on a Hertzsprung-Russell diagram, a type of chart that summarizes nearly everything that astronomers know about stars. Because of the scaling laws discussed above, stars in their main-sequence phase fall on a slanted line. When the star becomes a red giant, it turns off the main sequence onto a nearly horizontal line [*see illustration on page 45*].

Unfortunately, although astronomers can deduce the total lifetime of a star, it is hard to gauge how many years an individual star has already lived. A star in its prime is a paragon of stability. It must be younger than its theoretical life span, but researchers cannot pin down its age with much certainty. Only when a star enters the twilight of its life does it begin to change dramatically and thereby give away its age. For this reason, astronomers generally estimate stellar ages by looking at entire populations of stars that were born at approximately the same time. Such a group of stars is as old as its oldest members—the ones that have turned off the main sequence and entered their red-giant phase.

Timing the Old-Timers

A SPECIAL CLASS of star group, the globular cluster, seems to include some of the oldest stars in our galaxy. Globular clusters are compact and dense, consisting of 100,000 to a few million stars in a ball 100 light-years across. The night sky from an imaginary planet in a globular cluster would be a spectacular sight, filled with more than 100,000 stars visible to the naked eye. In contrast, only 6,000 stars are visible to the naked eye on Earth [see "Globular Clusters," by Ivan R. King; SCIENTIFIC AMERICAN, June 1985].

Whereas the sun and 75 percent of the Milky Way's other stars lie in a flattened disk, globulars reside in a spherical "halo" that surrounds the disk. Other big galaxies also contain globulars, and they are distributed in much the same way. The location is an important clue to the age of the clusters. In the 1930s German-born astronomer Walter Baade showed that the stars in our galaxy fall into two general categories. Bright blue stars—which, being massive, must be young—are found only in the disk. The stars in the halo tend to be fainter and redder. Baade did not know what caused this difference and simply labeled the bright blue stars "Population I" and the faint red stars "Population II." We now

ONE BIG—VERY BIG—HAPPY FAMILY, the gargantuan globular cluster G1 lies on the outskirts of the Andromeda galaxy. A younger and different type of star cluster, the Quintuplet cluster, is near the center of our own galaxy (*opposite page*). In both cases, all the stars were born at the same time.

R. MICHAEL RICH, KENNETH J. MIGHELL AND JAMES D. NEILL *Columbia University*; WENDY L. FREEDMAN *Carnegie Observatories* AND NASA *(left)*; DONALD F. FIGER *Space Telescope Science Institute* AND NASA *(right)*

brightness and temperature—that is, the same mass and age. On a Hertzsprung-Russell diagram, this congruence shows up as a sharp edge to the distribution of main-sequence stars. The less massive, longer-lived stars are plentiful, but the heavier stars are all gone, having become red giants. This abrupt cutoff confirms that the stars in the cluster all formed at the same time.

Wrinkled, Wrinkled, Little Star

GIVEN THESE PROPERTIES, determining the age of a globular cluster should be a straightforward exercise. Astronomers construct a Hertzsprung-Russell diagram for a large sample of stars in the cluster. The diagram reveals which stars have just exhausted their main fuel supply. The luminosity and temperature of those stars imply a certain mass and age, according to theoretical models. But the task is complicated by three factors: sensitivity to the exact stellar composition, details of the stellar models, and uncertainties in the conversion of observed brightness to intrinsic luminosity.

Although metals constitute a meager fraction of a star, they exert a disproportionate effect on its structure. These elements contribute to the star's gravity but do not undergo fusion. They gum up the nuclear engine, increasing the temperature in the core of the star. Moreover, metals are good absorbers of light, so they make it more difficult for the star to release its energy into space. The absorption causes the star to bloat; the same energy output is spread over a larger surface area, so the surface temperature decreases. Together these two effects mean that a metal-poor star will appear brighter and hotter than a metal-rich star of the same mass. If astronomers overestimate a star's metal content, they underestimate its mass and age.

To ascertain the composition of a star, observers analyze its spectrum. The rainbow of colors is etched with black lines of distinctive wavelengths, depending on the presence of different elements in the star's outermost layers. Over the past 20 years the advent of large ground-based telescopes, along with the introduction of sensitive electronic detectors, has allowed astronomers to obtain spectra with much higher resolution and signal-to-noise ratios. The measurement errors have shrunk by more than a factor of three. Using the Keck Observatory, Judith G. Cohen of the California Institute of Technology, Raffaele G. Gratton of the Astronomical Observatory of Padua and their collaborators recently determined the metal abundance in the globular clusters NGC 6528 and NGC 6553 with unprecedented precision.

Like a dying old town emptied of its young, the HALO OF OUR GALAXY is home only to the elderly.

know the reason: the disk contains lots of gas clouds, leading to lots of star formation and lots of young, flamboyant stars. The halo of our galaxy lacks gas, so few new stars form there. Like a dying old town emptied of its young, the halo is home only to the elderly.

In fact, globulars may be the leftover building blocks of our galaxy. Their stars contain just trace amounts of the elements heavier than helium. Called metals by astronomers (to the consternation of chemists), these elements constitute about 2 percent of the mass of the sun but a mere 0.01 to 0.5 percent of the mass of a globular star. Apart from lithium, such elements can be created only by stars; their paucity indicates that globulars formed soon after the big bang, from material that had not yet had much time to be polluted by generations of stars.

Within a given globular cluster, all the stars that have just exhausted the hydrogen in their core have nearly the same

The second complication is that theoretical models are approximations of what really goes on inside a star. For several years now, studies of the sun have revealed those limitations. Solar sound waves, for example, indicate that helium is slowly sinking toward the center of the sun, as Jørgen Christensen-Dalsgaard of the University of Århus in Denmark, David B. Guenther of Saint Mary's University in Nova Scotia and others have shown. The helium displaces hydrogen, reducing the amount of fuel that the sun has at its disposal and therefore its life expectancy. My colleagues and I have also refined the modeling of other processes

THE AUTHOR

BRIAN C. CHABOYER has been fascinated by space ever since he was four years old and watched the *Apollo 11* moon landing on TV. He obtained his Ph.D. at Yale University working under the supervision of Pierre Demarque, who was one of the first researchers to study the evolution of metal-poor stars. Chaboyer is now a professor in the department of physics and astronomy at Dartmouth College, a principal investigator on NASA's Space Interferometry Mission and an avid hockey player (he is Canadian by birth).

such as convection and have improved the description of how the gas responds to changes in pressure and temperature. The net effect has been to reduce the estimated globular ages by 14 percent. Stellar models now do an excellent job of explaining the sun, so it is hard to know how much more they can be refined.

The Age of Uncertainty

THE THIRD AND WORST ambiguity in stellar-age estimates is the luminosity of the stars. The observed brightness of a star depends on its distance as well as its intrinsic luminosity. But measuring distances is one of the most difficult tasks in astronomy. All the stars appear to lie on the surface of the sky, without any sense of depth from us. To add the third dimension, astronomers must rely on a variety of overlapping techniques, each of which works for objects in a certain range of distances.

The first rung in this distance ladder is parallax—the apparent shifting in position as you move your vantage point. The classic demonstration of parallax is to extend your arm, hold up one finger and alternately close your left and right eyes. Your finger will appear to jump back and forth against the background, simply because your two eyes view your finger from opposite sides of your nose. Bring your finger closer to your face, and you will notice that the parallax increases. Nearer objects exhibit larger parallaxes than farther ones do.

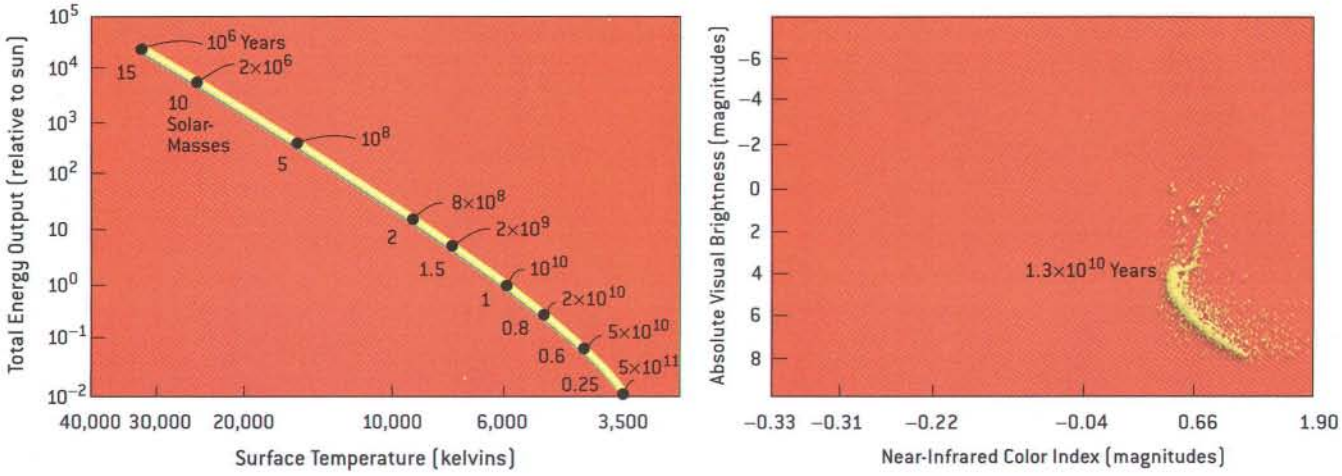
To measure parallaxes to stars, astronomers observe their locations during the course of a year. From different places in Earth's orbit, nearby stars appear to shift back and forth relative to distant stars. Astronomers measure this stellar parallax as an angle, which, when combined with the diameter of Earth's orbit (itself determined by parallax of bodies within the solar system), implies a distance. A star that shifts by one arcsecond over three months is, by definition, one parsec (3.26 light-years) away. According to basic trigonometry, the parallax is inversely proportional to the distance. Typical ground-based telescopes can discern a parallax of about 0.01 arcsecond, so they gauge distances with a precision of 10 percent out to 10 parsecs.

For the first time in half a century, cosmologists and STELLAR ASTROPHYSICISTS are in agreement.

By galactic standards, 10 parsecs is a bit of a joke. Moreover, the errors worsen systematically with distance: telescopes working at the limit of their resolution tend to overstate small parallaxes and thus understate distance. To put cosmic distances onto a firmer foundation, in 1989 the European Space Agency (ESA) launched the Hipparcos satellite on a four-year mission where no ground-based telescope had gone before. With an accuracy of around 0.001 arcsecond, it reached stars 10 times farther away. Even that is not enough to reach the closest globular cluster, an estimated 2,000 parsecs away, but Hipparcos did pin down the distance to nearby metal-poor stars that resemble those in globulars. Assuming that these stars have the same intrinsic luminosity as globular stars of the

BORN UNTO TROUBLE, the new stars in the Orion A giant molecular cloud light up dust, squirt out jets of material and trigger shock waves.

TRAVIS A. RECTOR, BRENDA WOLPA AND GEORGE H. JACOBY *National Optical Astronomy Observatories*



HERTZSPRUNG-RUSSELL DIAGRAM shows that the energy output and temperature of middle-aged stars fall on a line, the "main sequence." As a star begins to die, it veers off (*left*). From the observed brightness and color of stars in the cluster NGC 6652 (*right*), astronomers have prepared such a diagram and pinpointed which stars are on the verge of dying. (Because of compositional differences, the main-sequence lines are slightly offset.)

same color, astronomers have been able to determine the distance to the globulars with greater precision than before.

Not as Old as You Look

THE RESULT has been surprising: globular clusters are about 10 percent farther away than previously thought. That makes them intrinsically more luminous and therefore younger. The new age estimates are not without controversy, however; the distance scale may still be inaccurate, and the stellar models may still be incomplete.

Astronomers have sought corroboration from other ways to measure distance. One such method is to examine the motions of a large number of stars in a globular cluster. Each star's motion has two components: the radial velocity (along the line of sight) and the angular velocity (across the sky). Astronomers measure each component by independent means: the radial velocity by the Doppler effect; the angular velocity by photographs taken over the years. Because the apparent angular velocity depends on distance, whereas the radial velocity does not, any principle that connects the two will give the distance. For any individual star, the two components are entirely separate, but for a globular cluster, whose thousands of stars are moving randomly, the average radial velocity should equal the average angular velocity. In this way, astronomers have estimated the distances to globulars.

This method suggests that Hipparcos overestimated the distances. Currently the best guess is that the oldest globular cluster stars are 13 billion years old, plus or minus 1.5 billion years. This revised age estimate agrees quite nicely with the estimated age of the universe based on the most recent observations of its expansion rate. For the first time since the birth of modern cosmology half a century ago, cosmologists and stellar astrophysicists are in agreement.

Although globular dating is the primary way to estimate the age of the galaxy, other lines of evidence give roughly similar values. Earlier this year Roger Cayrel of the Paris Observatory and his colleagues applied a technique that archaeologists and geologists have long used on Earth: radioisotope dating. His team made the first measurements of uranium in a star other than our sun, an ancient Population II star code-named CS 31082-001. The abundance of the very heaviest elements in this star is only 12 percent of that in the sun—except for thorium 232 and uranium 238. Assuming that thorium and uranium also started off at 12 percent of solar abundance, 12.5 billion years (plus or minus three billion years) must have passed for these radioactive isotopes to decay to their current amounts. Eventually radioisotopes may displace globulars as the preferred dating technique.

In the meantime, the focus will be on firming up the globular cluster estimates. New ground-based telescopes such as the European Southern Observatory's Very Large Telescope promise to reduce the uncertainty in the composition of globular stars. New orbiting observatories, such as ESA's Gaia satellite and the National Aeronautics and Space Administration's Space Interferometry Mission, are scheduled for launch later this decade. With 250 times better resolution than Hipparcos, they should be able to cut out the stellar middlemen, determine the distance to globulars directly, and finally settle a question that has dogged astronomers for decades.

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AARON FIRTH

BEHIND ENEMY LINES

A close look at the inner workings of microbes in this era of escalating ANTIBIOTIC RESISTANCE is offering new strategies for designing drugs

by K. C. Nicolaou and Christopher N. C. Boddy • Photographs by Eric O'Connell

CHEMISTS ARE SEEKING to overcome bacteria such as vancomycin-resistant enterococci (*petri dish at right*) that now grow easily in the presence of vancomycin (*left*).

In the celebrated movie *Crouching Tiger, Hidden Dragon,* two warriors face each other in a closed courtyard whose walls are lined with a fantastic array of martial-arts weaponry, including iron rods, knives, spears and swords.

The older, more experienced warrior grabs one instrument after another from the arsenal and battles energetically and fluidly with them. But one after another, the weapons prove useless. Each, in turn, is broken or thrown aside, the shards of an era that can hold little contest against a young, triumphant, upstart warrior who has learned not only the old ways but some that are new.

One of the foundations of the modern medical system is being similarly overcome. Health care workers are increasingly finding that nearly every weapon in their arsenal of more than 150 antibiotics is becoming useless. Bacteria that have survived attack by antibiotics have learned from the enemy and have grown stronger; some that have not had skirmishes themselves have learned from others that have. The result is a rising number of antibiotic-resistant strains. Infections—including tuberculosis, meningitis and pneumonia—that would once have been easily treated with an antibiotic are no longer so readily thwarted. More and more bacterial infections are proving deadly.

Bacteria are wily warriors, but even so, we have given them—and continue to give them—exactly what they need for their stunning success. By misusing and overusing antibiotics, we have encouraged super-races of bacteria to evolve. We don't finish a course of antibiotics. Or we use them for viral and other inappropriate infections—in fact, researchers estimate that one third to one half of all antibiotic prescriptions are unnecessary. We put 70 percent of the antibiotics we produce in the U.S. each year into our livestock. We add antibiotics to our dishwashing liquid and our hand soap. In all these ways, we encourage the weak to die and the strong to become stronger [see "The Challenge of Antibiotic Resistance," by Stuart B. Levy; SCIENTIFIC AMERICAN, March 1998].

Yet even absent the massive societal and medical misuse of these medications, the unavoidable destiny of any antibiotic is obsolescence. Bacteria—which grow quickly through many cell divisions a day—will always learn something new; some of the strongest will always survive and thrive. So we have had to become ever more wily ourselves.

In the past 10 years, long-standing complacency about vanquishing infection has been replaced by a dramatic increase in antibacterial research in academic, government and industrial laboratories. Scientists the world over are finding imaginative strategies to attack bacteria. Although they will have a limited life span, new antibiotics are being developed using information gleaned from genome and protein studies. This exciting research and drug development is no panacea, but if combined with the responsible use of antibiotics, it can offer some hope. Indeed, in April 2000 the Food and Drug Administration approved the first new kind of clinical antibiotic in 35 years—linezolid—and several agents are already in the pharmaceutical pipeline.

Dismantling the Wall

ALMOST ALL THE ANTIBIOTICS that have been developed so far have come from nature. Scientists have identified them and improved on them, but they certainly did not invent them. Since the beginning of life on this planet, organisms have fought over limited resources. These battles resulted in the evolution of antibiotics. The ability to produce such powerful compounds gives an organism—a fungus or plant or even another species of bacteria—an advantage over bacteria susceptible to the antibiotic. This selective pressure is the force driving the development of antibiotics in nature.

Our window onto this biological arms race first opened with the discovery of penicillin in 1928. Alexander Fleming of St. Mary's Hospital Medical School at London University noticed that the mold *Penicillium notatum* was able to kill nearby *Staphylococcus* bacteria growing in agar in a petri dish. Thus was the field of antibiotics born. By randomly testing com-

THE AUTHORS

K. C. NICOLAOU and *CHRISTOPHER N. C. BODDY* have worked together at the Scripps Research Institute in La Jolla, Calif., where Nicolaou is chairman of the department of chemistry and Boddy recently received his Ph.D. Nicolaou holds the Darlene Shiley Chair in Chemistry, the Aline W. and L. S. Skaggs Professorship in Chemical Biology and a professorship at the University of California, San Diego. His work in chemistry, biology and medicine has been described in more than 500 publications and 50 patents. Boddy's research has focused on the synthesis of vancomycin. He will soon be moving to Stanford University, where as a postdoctoral fellow he will continue work on antibiotics and anticancer agents. The authors are indebted to Nicolas Winssinger and Joshua Gruber for valuable discussions and assistance in preparing this article.

pounds, such as other molds, to see if they could kill bacteria or retard their growth, later researchers were able to identify a whole suite of antibiotics.

One of the most successful of these has been vancomycin, first identified by Eli Lilly and Company in 1956. Understanding how it works—a feat that has taken three decades to accomplish—has allowed us insight into the mechanism behind a class of antibiotics called the glycopeptides, one of the seven or so major kinds of antibiotics. This insight is proving important because vancomycin has become the antibiotic of last resort, the only remaining drug effective against the most deadly of all hospital-acquired infections: methicillin-resistant *Staphylococcus aureus*. And yet vancomycin's power—like that of the great, experienced warrior—is itself in jeopardy.

Vancomycin works by targeting the bacterial cell wall, which surrounds the cell and its membrane, imparting structure and support. Because human and other mammalian cells lack such a wall (instead their cells are held up by an internal structure called a cytoskeleton), vancomycin and related drugs are not dangerous to them. This bacterial wall is composed mostly of peptidoglycan, a material that contains both peptides and sugars (hence its name). As the cell assembles this material—a constant process, because old peptidoglycan needs to be replaced as it breaks down—sugar units are linked together by an enzyme called transglycosidase to form a structural core. Every other sugar unit along this core has a short peptide chain attached to it. Each peptide chain is composed of five amino acids, the last three being an L-lysine and two D-alanines. An enzyme called transpeptidase then hooks these peptide chains together, removing the final D-alanine and attaching the penultimate D-alanine to an L-lysine from a different sugar chain. As a result, the sugar chains are crocheted together through their peptide chains. All this linking and cross-linking creates a thickly woven material essential for the cell's survival: without it, the cell would burst from its own internal pressure.

Vancomycin meddles in the formation of this essential material. The antibiotic is perfectly suited to bind to the peptide chains before they are linked to one another by transpeptidase. The drug fastens onto the terminal D-alanines, preventing the enzyme from doing its work. Without the thicket of cross-linking connections, peptidoglycan becomes weak, like an ill-woven fabric. The cell wall rends, and cell death rapidly occurs.

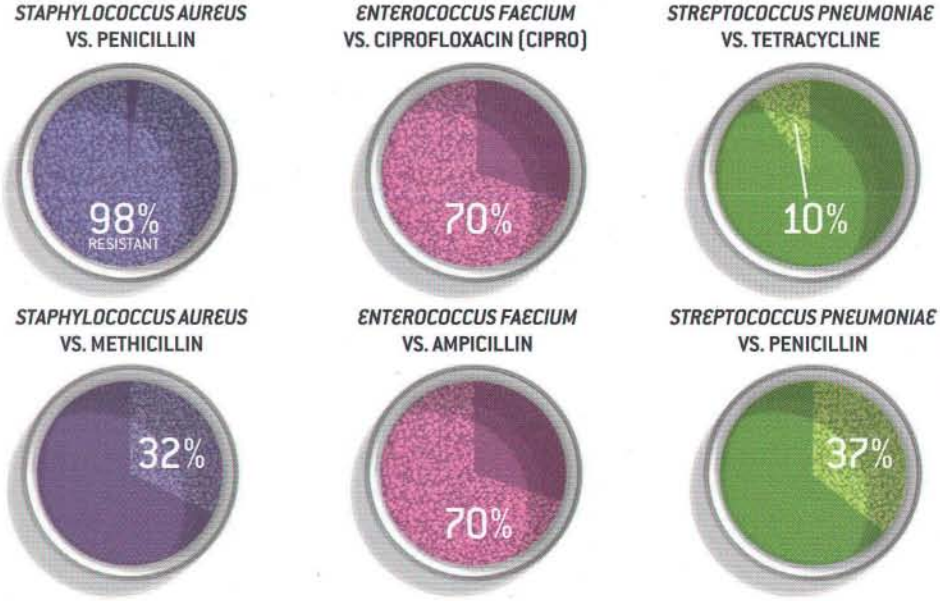
Resisting Resistance

VANCOMYCIN'S LOVELY FIT at the end of the peptide chain is the key to its effectiveness as an antibiotic. Unfortunately, its peptide connection is also the key to resistance on the part of bacteria. In 1998 vancomycin-resistant *S. aureus* emerged in three geographic locations. Physicians and hospital workers are increasingly worried that these strains will become widespread, leaving them with no treatment for lethal staph infections.

Understanding resistance offers the possibility of overcoming it, and so scientists have focused on another bacterium that has been known to be resistant to the powerful drug since the late 1980s: vancomycin-resistant enterococci (VRE). In most enterococci bacteria, vancomycin does what it does best: it binds to the terminal two D-alanines. At a molecular level, this binding entails five hydrogen bonds—think of them as five fingers clasping a ball. But in VRE, the peptide chain is slightly different. Its final D-alanine is altered by a simple substitution: an oxy-

RISING RESISTANCE

MANY ANTIBIOTICS are no longer effective against certain strains of bacteria, as these examples—collected from different hospitals in the late 1990s—show. One strain of *Staphylococcus aureus* found in Korea, for instance, is 98 percent resistant to penicillin (*top left*); another, found in the U.S., is 32 percent resistant to methicillin (*bottom left*). All these strains are not resistant to vancomycin, for now.



SLIM FILMS

COMPOUNDS are mixed in the chemist's workspace under the fume hood. In the setup to the left, organic molecules are being purified. In the two to the right, reactions occur in the presence of argon gas, which is in the balloons and which protects sensitive molecules from oxygen and water in air.

New methods in combinatorial chemistry facilitate the RAPID DESIGN of huge libraries of compounds.

gen replaces a pair of atoms consisting of a nitrogen bonded to a hydrogen. In molecular terms, this one substitution means that vancomycin can bind to the peptide chain with only four hydrogen bonds. The loss of that one bond makes all the difference. With only four fingers grasping the ball, the drug cannot hold on as well, and enzymes pry it off, allowing the peptide chains to link up and the peptidoglycan to become tightly woven once again. One atomic substitution reduces the drug's activity by a factor of 1,000.

Researchers have turned to other members of the glycopeptide class of antibiotics to see if some have a strategy that vancomycin could adopt against VRE. It turns out that some members of the group have long, hydrophobic—that is, oily—chains attached to them that have proved useful. These chains prefer to be surrounded by other hydrophobic molecules, such as those that make up the cell membrane, which is hidden behind the protective peptidoglycan shield. Researchers at Eli Lilly have borrowed this idea and attached hydrophobic chains to vancomycin, creating an analogue called LY333328. The drug connects to the cell membrane in high concentrations, allowing it more purchase and, as a consequence, more power against peptidoglycan. This analogue is effective against VRE and is now in clinical trials.

Other glycopeptide antibiotics use a different strategy: dimerization. This process occurs when two molecules bind to each other to form a single complex. By creating couples, or dimers, of vancomycin, researchers can enhance the drug's strength. One vancomycin binds to peptidoglycan, bringing the other half of the pair—the other molecule of vancomycin—into proximity as well. The drug is more effective because more of it is present. One of the aims of our laboratory is to alter vancomycin so it pairs up more readily, and we have recently developed a number of dimeric vancomycin molecules with exceptional activity against VRE.

Even so, the good news may be short-lived. A second mechanism by which VRE foils vancomycin has recently been discovered. Rather than substituting an atom in the final D-alanine, the bacterium adds an amino acid that is much larger than D-alanine to the very end of the peptide chain. Like a muscular bouncer blocking a doorway, the amino acid prevents vancomycin from reaching its destination.

One method by which the deadly *S. aureus* gains resistance is becoming clear as well. The bacterium thickens the peptidoglycan layer but simultaneously reduces the linking between the peptide fragments. So it makes no difference if vancomycin binds to D-alanine: thickness has replaced interweaving as the source of the peptidoglycan's strength. Vancomycin's meddling has no effect.

The Cutting Edge

AS THE STORY of vancomycin shows, tiny molecular alterations can make all the difference, and bacteria find myriad strategies to outwit drugs. Obviously, the need for new, improved or even revived antibiotics is enormous. Historically, the drug discovery process identified candidates using whole-cell screening, in which molecules of interest were applied to living bacterial cells. This approach has been very successful and underlies the discovery of many drugs, including vancomycin. Its advantage lies in its simplicity and in the fact that every possible drug target in the cell is screened. But screening such a large number of targets also has a drawback. Various targets are shared by both bacteria and humans; compounds that act against those are toxic to people. Furthermore, researchers gain no information about the mechanism of action: chemists know that an agent worked, but they have no information about how. Without this critical information it is virtually impossible to bring a new drug all the way to the clinic.

Molecular-level assays provide a powerful alternative. This form of screen identifies only those compounds that have a specified mechanism of action. For instance, one such screen would look specifically for inhibitors of the transpeptidase enzyme. Although these assays are difficult to design, they yield potential drugs with known modes of action. The trouble is that only one enzyme is usually investigated at a time. It would be a vast improvement in the drug discovery process if researchers could review more than one target simultaneously, as they do in the whole-cell process, but also retain the implicit knowledge of the way the drug works. Scientists have accomplished this feat by figuring out how to assemble the many-enzyme pathway of a certain bacterium in a test tube. Using this system, they can identify molecules that either strongly disrupt one of the enzymes or subtly disrupt many of them.

Automation and miniaturization have also significantly improved the rate at which compounds can be screened. Robotics in so-called high-throughput machines allow scientists to review thousands of compounds per week. At the same time, miniaturization has cut the cost of the process by using ever smaller amounts of reagents. In the new ultrahigh-throughput screening systems, hundreds of thousands of compounds can

be looked at cost-effectively in a single day. Accordingly, chemists have to work hard to keep up with the demand for molecules. Their work is made possible by new methods in combinatorial chemistry, which allows them to design huge libraries of compounds quickly [see "Combinatorial Chemistry and New Drugs," by Matthew J. Plunkett and Jonathan A. Ellman; SCIENTIFIC AMERICAN, April 1997]. In the future, some of these new molecules will most likely come from bacteria themselves. By understanding the way these organisms produce antibiotics, scientists can genetically engineer them to produce new related molecules.

The Genomic Advantage

THE METHODOLOGY of drug design and screening has benefited tremendously from recent developments in genomics. Information about genes and the synthesis of their proteins has allowed geneticists and chemists to go behind enemy lines and use inside information against the organism itself. This microbial counterintelligence is taking place on several fronts, from sabotaging centrally important genes to putting a wrench in the production of a single protein and disrupting a bacterium's ability to infect an organism or to develop resistance.

Studies have revealed that many of the known targets of antibiotics are essential genes, genes that cause cell death if they are not functioning smoothly. New genetic techniques are making the identification of these essential genes much faster. For instance, researchers are systematically analyzing all 6,000 or so genes of the yeast *Saccharomyces cerevisiae* for essential genes. Every gene can be experimentally disrupted and its effect on yeast determined. This effort will ultimately catalogue all the essential genes and will also provide insight into the action of other genes that could serve as targets for new antibiotics.

The proteins encoded by essential genes are not the only molecular-level targets that can lead to antibiotics. Genes that encode for virulence factors are also important. Virulence factors circumvent the host's immune response, allowing bacteria to colonize. In the past, it has been quite hard to identify these genes because they are "turned on," or transcribed, by events in the host's tissue that are very difficult to reproduce in the laboratory. Now a technique called in vivo expression technology (IVET) can insert a unique sequence of DNA, a form of tag that deactivates a gene, into each bacterial gene. Tagged bacteria are then used to infect an organism. The bacteria are later recovered and the tags identified. The disappearance of any tags means that the genes they were attached to were essential for the bacteria's survival—so essential that the bacteria could not survive in the host without the use of those genes.

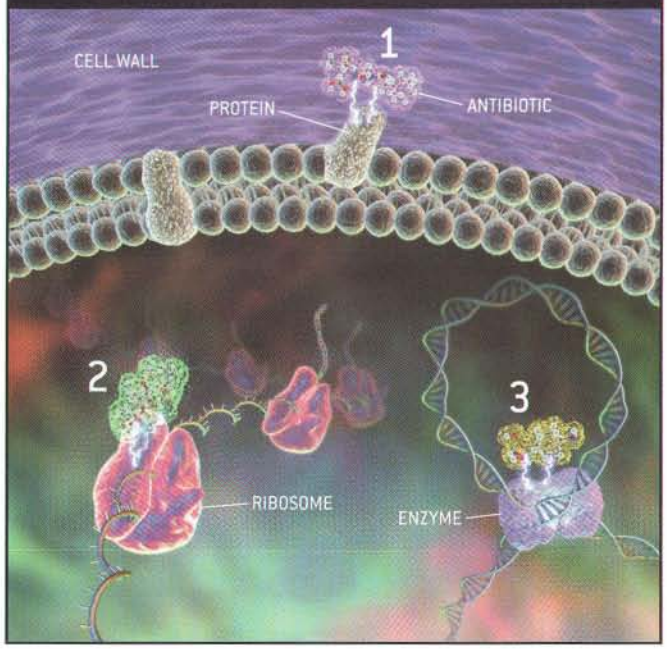
Investigators have long hoped that by identifying and inhibiting these virulence factors, they can allow the body's immune system to combat pathogenic bacteria before they gain a foothold. And it seems that the hypothesis is bearing fruit. In a recent study, an experimental molecule that inhibited a virulence factor of the dangerous *S. aureus* permitted infected mice to resist and overcome infection.

In addition to identifying essential genes and virulence factors, researchers are discovering which genes confer antibiotic resistance. Targeting them provides a method to rejuvenate previously ineffective antibiotics. This is an approach used with ß-lactam antibiotics such as penicillin. The most common mechanism of resistance to ß-lactam antibiotics is the bacterial production of an enzyme called ß-lactamase, which breaks one of the antibiotic's chemical bonds, changing its structure and preventing it from inhibiting the enzyme transpeptidase. If ß-lactamase is silenced, the antibiotics remain useful. A ß-lactamase inhibitor called clavulanic acid does just that and is mixed with amoxicillin to create an antibiotic marketed as Augmentin.

In the near future, with improvements in the field of DNA transcriptional profiling, it will become routine to identify resistance determinants, such as ß-lactamase, and virulence factors. Such profiling allows scientists to identify all the genes that are in use under different growth conditions in the cell. Virulence genes can be determined by identifying bacterial genes whose expression increases on infecting a host. Genes that code for antibiotic resistance can be determined by comparing expression

ANTIBIOTICS AT WORK

EXISTING ANTIBIOTICS fight infections by preventing bacteria from making essential substances. Vancomycin and ß-lactam antibiotics interfere with synthesis of the cell wall (*1*). Erythromycin and tetracycline disrupt ribosomes that make proteins (*2*). Quinolone antibiotics inhibit enzymes involved in replicating DNA (*3*), and sulfonamide antibiotics also interfere with DNA synthesis (*not shown*).



JEFF JOHNSON

Vancomycin's power—like that of the great, EXPERIENCED WARRIOR—is itself in jeopardy.

levels in bacteria treated with the antibiotic and those not treated. Though still in its infancy, this technique monitored tiny changes in the number of transcription events. With DNA transcriptional profiling, researchers should also be able to determine whether certain drugs have entirely new mechanisms of action or cellular targets that could open up new fields of antibiotic research.

Killing the Messenger

ANOTHER INTERESTING LINE of genomic research entails interfering with bacterial RNA. Most RNA is ribosomal RNA (rRNA), which forms a major structural component of ribosomes, the cellular factories where proteins are assembled. Ribosomal RNA is vulnerable because it has various places where drugs can attach and because it lacks the ability to repair itself. In 1987 scientists determined that antibiotics in the aminoglycoside group—which includes streptomycin—bind to rRNA, causing the ribosome to misread the genetic code for protein assembly. Many of these antibiotics, however, are toxic and have only limited usefulness. Recently scientists at the Scripps Research Institute in La Jolla, Calif., have reported a new synthetic aminoglycoside dimer that may have less toxicity.

Investigators can also interfere with messenger RNA (mRNA), which directs the assembly of proteins and travels between the genetic code and the ribosome. Messenger RNA is created by reading one strand of the DNA, using the same nucleic acid, or base pair, interactions that hold the double helix together. The mRNA molecule then carries its message to the ribosome, where a protein is assembled through the process of translation. Because each mRNA codes for a specific protein and is distinct from other mRNAs, researchers have the opportunity to create interactions between small organic molecules—that is, not proteins—and specific mRNAs. Parke-Davis chemists have been able to use such an approach to combat HIV infection. They identified molecules that bind to a part of an mRNA sequence and prevent it from interacting with a required protein activator, thus inhibiting the replication of HIV. This proof-of-principle experiment should help pave the way for further studies of mRNA as a drug development target.

Scientific interest has been intense in another approach, called antisense therapy. By generating sequences of nucleotides that bind perfectly with a specific mRNA sequence, investigators can essentially straitjacket the mRNA. It cannot free itself from the drug, which either destroys it or inhibits it from acting. Although the FDA has recently approved the first antisense drug to treat human cytomegalovirus infections, antisense for bacterial infections has not succeeded yet for several reasons, including toxicity and the challenge of getting enough of the drug to the right spot. Nevertheless, the approach holds promise.

As is clear, all these genomic insights are making it possible to identify and evaluate a range of new biological targets against which chemists can direct their small, bulletlike molecules. A number of antibiotics developed in the past century cannot be used, because they harm us. But by comparing a potential target's genetic sequence with the genes found in humans, researchers can identify genes that are unique to bacteria and can focus on those. Similarly, by comparing a target's genetic sequence to those of other bacteria, they are able to evaluate the selectivity of a drug that would be generated from it. A target sequence that appears in all bacteria would very likely generate an antibiotic active against many different bacteria: a broad-spectrum antibiotic. In contrast, a target sequence that appears in only a few bacterial genomes would generate a narrow-spectrum antibiotic.

If physicians can identify early on which strain is causing an infection, they can hone their prescription to a narrow-spectrum antibiotic. Because this drug would affect only a subset of the bacterial population, selective pressure for the development of resistance would be reduced. Advances in the high-speed replication of DNA and transcriptional profiling may soon make identification of bacterial strains a routine medical procedure.

Although the picture looks brighter than it has for several decades, it is crucial that we recognize that the biological arms race is an ancient one. For every creative counterattack we make, bacteria will respond in kind—changing perhaps one atom in one amino acid. There will always be young warriors to challenge the old ones. The hope is that we exercise restraint and that we use our ever expanding arsenal of weapons responsibly, not relegating them so quickly to obsolescence. SA

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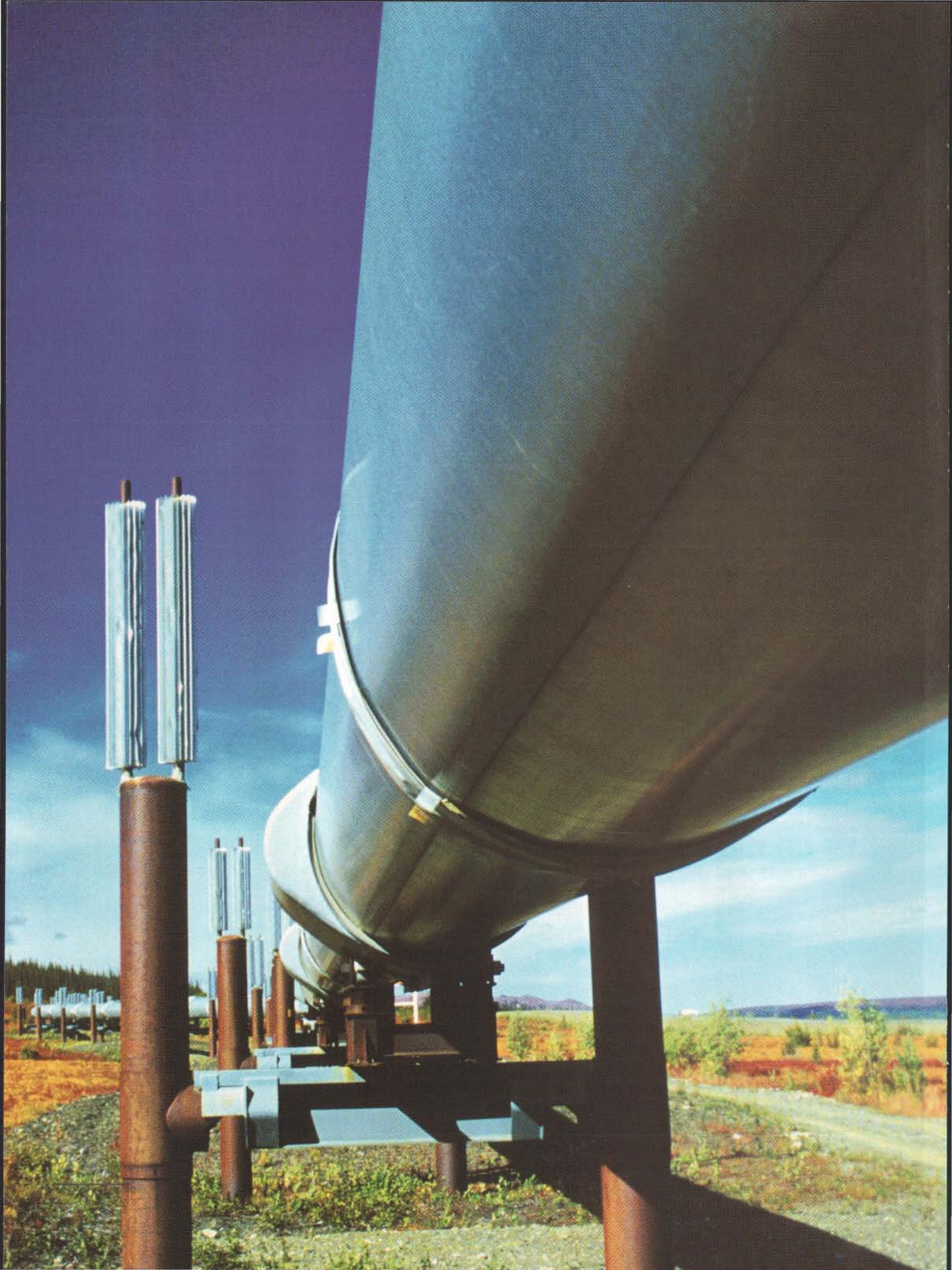

the arctic oil & wildlife refuge

THE LAST GREAT ONSHORE OIL FIELD IN AMERICA MAY LIE BENEATH THE NATION'S LAST GREAT COASTAL WILDERNESS PRESERVE. SCIENCE CAN CLARIFY THE POTENTIAL ECONOMIC BENEFITS AND THE ECOLOGICAL RISKS OF DRILLING INTO IT

BY W. WAYT GIBBS

JIM BARR

Flying from Deadhorse, Alaska, west to Phillips Petroleum's new Alpine oil field, you can watch the evolution of oil development on the North Slope scroll below like a time-lapse film. At takeoff, the scene fills with the mammoth field where it all began: Prudhoe Bay, discovered in 1968 and uncorked in 1977 to send its oil down the Trans-Alaska Pipeline to the ice-free port at Valdez.

Climbing higher, the plane tracks feeder pipelines that zig westward to Kuparuk, second only to Prudhoe among the most oil-rich onshore fields yet found in North America. Like Prudhoe, Kuparuk has grown since its opening in 1981 into a scattershot of gravel well pads connected over 800 square miles by a web of roads and pipes to giant processing plants, camp buildings, vehicle lots, and dark pits full of rock and mud drilled from the deep.

To the north, the artificial islands of Northstar and Endicott appear just offshore. And as the flight descends onto the airstrip at Alpine, you fast-forward to the state of the art in petroleum engineering. Industry executives often cite this nearly roadless, 94-acre project as a model of environmentally and financially responsible oil development, proof that oil companies have learned how to coexist with delicate Arctic ecosystems.

Alpine is the newest and westernmost of the North Slope oil fields, but not for long. When its valves opened in November 2000, crude oil flowed the 50 miles back to Pump Station 1 near Deadhorse—as all oil produced on the slope must—via a new tributary to the pipeline system. By February, Alpine's production had already hit the plant's maximum output of almost 90,000 barrels a day. But the pipe to Deadhorse can carry much more.

It was built with the future in mind, and from Alpine the future of the hydrocarbon industry on the North Slope heads in three directions at once. It will continue westward, into the 23-million-acre National Petroleum Reserve–Alaska (NPR-A) on which Alpine borders. The federal government put four million acres up for lease in 1999, and exploration began last year. New fields there will deliver their oil through Alpine's pipe.

The future may lead southward as well. Soaring gas prices spurred North Slope companies last year to commit $75 million to plan a $10-billion natural gas pipeline that would open some 35 trillion cubic feet of untapped reserves to the lower American states by the end of the decade.

Beyond 2010, Phillips, BP and the other Alaskan oil producers look toward the east for new opportunities. Not 30 miles past Badami, the eastern terminus of the North Slope infrastructure, lie the coastal plain and tussock tundra of the so-called 1002 Area. It is named for the section of the Alaska National Interest Lands Conservation Act of 1980 that set aside 1.5 million acres of federal property in deference to geologists' guesses that the region entombs billions of barrels of oil and trillions of cubic feet of gas.

The same act placed the 1002 Area inside the 19-million-acre Arctic National Wildlife Refuge (ANWR), in deference to biologists' observations that the coastal plain provides a pre-

The Debate / *Oil vs. Wildlife*

- Senate bill S. 389 would open the coastal plain and foothills of the Arctic National Wildlife Refuge, the so-called 1002 Area, to oil development. A competing bill, S. 411, would designate the area as wilderness, prohibiting development.
- Geologists have used 1985 seismic data to estimate how much profitable oil and gas lie below the surface. But before any lease sale, oil companies would conduct new seismic surveys. That would leave a grid of visible scars in the vegetation of the plain but would have little or no effect on wildlife.
- Ice roads and exploration wells would follow. Fish and waterfowl may suffer if rivers and lakes are overdrained.
- A network of oil fields, processing plants and pipelines would extract the oil. A nearly roadless development may have little effect on the herd of 130,000 caribou that calves on the plain. Or it may displace the animals, affecting their nutrition, predation and birth rates, and long-term population growth.

LAURIE GRACE

ARCTIC REFUGE provides valuable calving ground for the Porcupine caribou herd. Ecologists argue that it also has intrinsic value as a "control area" against which they can compare the environmental effects of human development.

mium Arctic habitat: calving ground for the Porcupine caribou herd; nesting and staging wetlands for tundra swans and other migratory waterfowl; dens for polar bears and arctic foxes; and year-round forage for a small herd of muskoxen.

Congress thus instigated one of the longest-running environmental turf wars of the past century, and the darts have again begun to fly. On February 26, Senator Frank H. Murkowski of Alaska introduced S. 389, a bill that would open the 1002 Area to oil and gas exploration and production. The bill allows the Bureau of Land Management to restrict the activities to ensure that they "will result in no significant adverse effect on the fish and wildlife, their habitat, subsistence resources and the environment."

Can careful regulation prevent such effects? Or does even the most compact, high-tech, thoroughly monitored oil development pose an unacceptable risk to the largest American wildlife refuge remaining so close to its natural condition?

It is a mistake to ask scientists questions that force them to weigh the relative values of oil and wilderness. Some 245 biologists, not waiting to be asked, signed an open letter to President Bill Clinton last November urging him to bypass Congress and declare the area a wilderness, which would close it to development. In interviews with numerous Alaskan petroleum geologists, on the other hand, virtually all asserted that the oil industry could move in without causing more than cosmetic damage. In a fundamentally political dispute, scientists' opinions should carry no more weight than anyone else's.

Science and engineering should enter the debate over the fate of the Arctic refuge, however—not as a lobby but as a source of facts that all positions must accommodate. Thirty years of innovation has produced less disruptive ways of finding and removing the oil below the tundra. And 25 years of biology has quantified how those activities disturb the life on its surface. Before the public decides the question, it should have the clearest picture possible of what it might gain, what it might risk in the gamble—and what uncertainties are tucked into the word "might."

What Lies Beneath

AT LEAST EIGHT SEPARATE GROUPS of geologists have tried over the years to guess how much oil and gas sit below the 1002 Area in forms and places that would allow them to be recovered with current technology and at realistic prices. All eight teams relied on a single set of data from a seismic survey made in the winters of 1984 and 1985. Long rows of low-frequency microphones were set down on the snow to capture the echoes of sound-generating trucks up to a mile away as the sound waves bounced off rock layers at various depths. The string of microphones was moved, the process was repeated, and 1,450 miles of cross-sectional snapshots were taken, covering the entire 1002 Area in a rough three-by-six-mile grid.

Turning those recordings into pictures of the subsurface and then inferring from the pictures which formations hold what quantity of oil is as much an art as it is a science. "The source rocks, trap formations [that hold the oil in place] and extent of migration all must be estimated based on analogies and prior experience," explains Mark D. Myers, director of the oil and

A Model of a Modern Major Oil Field

SUBSURFACE NOT TO SCALE

REMOVING OIL from the Arctic refuge would probably require four or more Alpine-size fields. Processing plants, split into 1,500-ton modules (*1*), would be hauled on ice roads (*2*) built with water removed from nearby lakes and sprayed on the frozen tundra. Each seven-foot-thick gravel pad, accessible in summer only by air, would hold up to 60 closely spaced wellheads. Drilled by 150-foot-tall derricks or smaller coiled tubing rigs (*3*), the wells would penetrate the permafrost and then veer to run horizontally through oil pockets up to six miles away. Half or more of the wells would inject seawater or natural gas into the rock to push oil toward producing wells nearby. A central processing facility would remove water and gas from the flow of satellite fields up to 30 miles distant, then pump all the oil through a pipeline to Prudhoe Bay. The pipe could be buried under rivers and elevated five feet above the tundra to allow caribou and muskoxen to pass. Regularly spaced "loops" (*4*) would halt flow automatically if a large leak occurred. About 300 crew members would run the facility year-round.

In wintertime, large convoys of roughly 100 workers, eight to 10 sound-generating trucks (*5*) and three dozen other vehicles would crisscross the frozen tundra, shooting seismic surveys. Other teams of 100 or so would pour ice pads, drive two-million-pound mobile drill rigs onto them, then rush to complete wildcat wells (*6*) before the spring thaw in April.

ILLUSTRATION BY DAVID FIERSTEIN; PHOTOGRAPHS BY PHILLIPS ALASKA, INC. (*1, 4, 5, 6*); JUDY PATRICK (*2, 3*)

gas division of Alaska's Department of Natural Resources. Wesley K. Wallace, a geologist at the University of Alaska, Fairbanks (U.A.F.), ticks off more unknowns: "size of the formation, thickness, porosity—each has an error bar," sometimes a very large one, and even the size of the error bars is subjective.

No wonder, then, that the eight independent studies arrived at widely divergent estimates. Differences in their methods make it useless to compare them. But by all accounts, the best assessment to date is the latest one, led by Kenneth J. Bird of the U.S. Geological Survey (USGS). From 1996 to 1998 Bird and his teammates ran the old seismic data through new computer models. They gathered logs and rock samples from 41 wells drilled over the years near the borders of the refuge. They looked again at outcrops where oil-stained rock breaks through the permafrost and traveled to the adjacent mountains where some likely reservoir strata are uplifted and exposed. And they looked at the reflectance of vitrinite and the tracks made by radioactive nuclei in apatite found in the 1002 Area for clues to those minerals' temperature history, which matters because hydrocarbons turn into oil only when cooked just so.

The result is not one estimate but several, because the relevant figure is not how much oil is there but how much can be profitably recovered—and that depends in turn on the price of oil. Bird's group concluded that thorough exploration would most likely yield about seven billion barrels (bbo) of economically recoverable oil if North Slope prices remain above $24 a barrel, where they were in March. The estimate falls to about 5 bbo if oil prices slip to $18, and it plummets to a few hundred million barrels if prices drop to $12. Since 1991 the price of North Slope crude has fluctuated between $9 and $35, averaging $18 a barrel. [*More information on the range of estimates is available at www.sciam.com/2001/0501issue/0501gibbs/*]

At 7 bbo, the 1002 Area would hold about half as much profitable petroleum as Prudhoe Bay did in 1977. But as with Prudhoe, the oil could be raised only over the course of several decades, following a classic bell-shaped curve. Industry insiders say that 10 years would probably pass between a decision to open the refuge to development and the first flow into the Alaskan pipeline. Environmental-impact studies and hearings would take two years, if the history of NPR-A is a guide. Companies would then have a year or two to do more intense seismic surveys and to prepare their bids on leases. Several years of exploration typically go into each discovery—after two years of drilling in NPR-A, for example, no strikes have been announced yet. Each permanent drilling site, processing facility and pipeline extension would have to clear more environmental analyses and hearings, and each would take two to three years to build.

An analysis by the U.S. Energy Information Administration (EIA) suggests that if the USGS estimate of 7 bbo is correct, then the 1002 Area will generate fewer than 200,000 barrels a day for the first five years. The EIA also forecasts that American petroleum consumption, 19.5 million barrels a day last year, will rise to 23 million by 2010, with 66 percent of that amount imported. At its peak, probably no earlier than 2030, complete development of the coastal plain of the Arctic refuge would produce about one million barrels of oil a day. Flow from the 1002 Area would then meet something shy of 4 percent of the nation's daily demand for petroleum [*see box on next page*].

There's the Rub

PETROLEUM GEOLOGISTS know what they need to do to reduce the huge uncertainties in the USGS analysis. "The first thing a company would do is shoot a new 3-D seismic survey," Myers says. With gaps in the previous seismic data of up to six miles wide, "every prospect drilled on the slope this year would be invisible on that [1985] survey," he observes. This time "the grid would be much finer," with lines spaced about 1,100 feet apart, says Michael Faust, geoscience technology manager for Phillips in Anchorage. With new, high-resolution data, supercomputers could model the subsurface in three-dimensional detail.

The caravan of survey equipment, however, would appear much the same as before, Faust says: typically, eight vibrating and seven recording vehicles, accompanied by personnel carriers, mechanic trucks, mobile shop trucks, fuel tankers, an incinerator, plus a crew of 80 to 120 people and a camp train of 20 to 25 shipping containers on skis, pulled by several Caterpillar tractors on treads. The crew would leave in January and stay out through April, returning the next winter if necessary to cover the entire 1002 Area, 1,100 feet at a time. Each interested oil company or partnership would shoot its own complete survey, employing its own caravan.

That prospect worries Martha K. Raynolds, a U.A.F. biologist. She and Janet C. Jorgenson, a botanist with the U.S. Fish and Wildlife Service in Fairbanks, have returned six times to monitor 200 patches of tundra that were randomly chosen for study as the last seismic vehicles passed over them 17 years ago. Ten percent still showed scuffing or reduced plant cover after 10 years, and 7 percent—about 100 miles of trail—had not recovered by 1998.

The problem, they say, is the terrain. The wide, low-pressure tires of the seismic trucks leave little trace on the flat, frozen, snow-covered grasslands around Prudhoe Bay and Alpine. Rubber treads on the tractors grip well enough. But east toward ANWR, the mountains march northward and the coast withdraws. That leaves the North Slope just 20 to 30 miles within the 1002 Area to attempt its typically gentle decline from rolling foothills to stream-crazed plateau to the ice-locked Beaufort Sea. Often it fails, and the tundra piles into hummocks. Winds clear the snow from their tops, exposing the dwarf willows and the standing dead vegetation. Tires and skis crush the shrubs and compact the sedges. Rubber treads lose traction on slopes, are replaced with steel and inevitably dig in, Jorgenson says.

At breakup in May, permafrost below the compacted areas thaws early, deprived of its usual insulation. Pools form, some native plant species die, and visitors take over. Three quarters of the vegetative scars were still visible from the air a decade after the survey; many appear to be permanent. But no research suggests that the changes affect wildlife, both scientists say.

What Harm in Looking?

SEISMIC SURVEYS GENERATE CLUES, not discoveries. For petroleum geologists, truth emerges only from holes in the ground. Once the supercomputers have spit out their images, exploration teams would fan out across the frozen 1002 Area to drill wildcat wells. A mobile drill rig like the one at Alpine weighs 2.2 million pounds, so it is driven and parked on thick slabs of ice made by laying down six-inch-deep piles of ice chips and cementing them with water.

With lots of water, in fact—about a million gallons per mile of road. Around Prudhoe, tens of thousands of lakes ensure that liquid water is plentiful even when the air drops to –20 degrees Fahrenheit. Twelve years ago, however, a thorough search of the 1002 Area in April—when the ice hits its maximum thickness of seven feet—turned up only nine million gallons of liquid water sequestered in ice pockets along 237 miles of the major interior rivers. Steve Lyons, chief hydrologist for the refuge, found 255 lakes, ponds and puddles within the 1002 Area. Just 59 of those were deeper than seven feet, and only eight contained enough unfrozen water to build a mile or more of ice road. The largest basins lie in the Canning and Jago river deltas, and their bottom water is often brackish and potentially poisonous to vegetation.

Allow those few wet lakes to freeze through in winter, Lyons predicts, and next summer the waterfowl that pause in their migration to feed on invertebrates in the ponds will find fewer to eat. Draw too heavily from the spring-fed Canning, which runs free year-round, and the many kinds of fish that overwinter there may suffer, he warns.

"Water in ANWR could be a problem," says Thomas Manson, the environmental manager at Alpine, which treats and recycles its freshwater but still runs through 70,000 gallons every day. The trouble is not only quantity but also distribution: as a rule, water is drawn no farther than 10 miles from where it is needed, or else it freezes in the trucks on the way. Lyons admits that there may be technological solutions, such as a desalinization plant connected to a heated, elevated pipeline. But such measures would change the economics of the enterprise and thus the amount of oil recoverable.

Facts / *Forecasting the Flow*

- Full development of the 1002 Area would most likely produce about seven billion barrels of profitable oil, according to a 1998 analysis by the U.S. Geological Survey, but only if North Slope oil prices remain above $24 a barrel.
- If the refuge were opened to exploration this year, oil production from the area would probably begin around 2010.
- The flow of oil would rise to a peak rate around 2030 of roughly one million barrels a day—just under 4 percent of U.S. daily consumption—according to the USGS analysis. An independent estimate by Jean Laherrère of Petroconsultants in Geneva put the peak flow at just over 700,000 barrels a day, however.
- ANWR also probably holds about four trillion cubic feet of natural gas within the 1002 Area, the USGS estimates. Gas production would require construction of a new gas pipeline to connect the North Slope to the lower 48 states.

(Wild)Life Goes On

OF COURSE, IF ANY OIL is to be recovered, plants must be built. "Put four or five Alpine-size fields into ANWR with the processing facilities to support them, and you're talking about a few thousand acres of development," Myers says. "Clearly, some habitat will be damaged or destroyed. The question is: How will that modify the behavior of the animals?"

Theoretically, oil development could affect animals in many ways. Drillers no longer dump their cuttings and sewage and garbage into surface pits; these are now either burned or injected deep into wells. That greatly reduces the impact on foxes and bears. But there are other emissions. Alpine sees six to eight aircraft pass through every day, some as large as a C-130 Hercules. The scents of up to 700 workers and the noise of numerous trucks and two enormous turbines, big as the engines of a 747, constantly waft out over the tundra. A 10-foot gas flare shimmers atop a 100-foot stack. And three pipelines—two bringing seawater and diesel fuel in, one pumping crude out—fly to the horizon at just over the height of a caribou's antlers.

How the animal inhabitants of the 1002 Area would react to a collection of Alpine-style oil developments is a puzzle to which biologists have only pieces of a solution. Some wildlife does seem to have been displaced around the oil fields at Prudhoe and Kuparuk. Tundra swans, for example, tend to nest more than 650 feet from the roadways there, and caribou with calves typically hang back 2.5 miles or more.

Brad Griffith of U.A.F.'s Institute of Arctic Biology recently found two important patterns in the distribution since 1985 of the 130,000 caribou of the Porcupine herd, which arrives in the 1002 Area almost every year by June to bear and wean its young before departing for warmer climes by mid-July. The first pattern is a strong correlation of calf survival with the amount of high-protein food in the calving area. Second, caribou cows with newborns have consistently concentrated in the most rapidly greening areas (as measured by satellite) during lactation. Scott Wolfe, a graduate student of Griffith's, last year showed that the second pattern holds as well for the half of the Central Arctic herd that calves east of the Sagavanirktok River.

Across that river lie the big oil fields, and Wolfe found that from 1987 to 1995 the western half of the herd shifted its calving concentrations southward, away from the growing development and the richest forage. Ray Cameron, another Institute biologist, worries that that movement may affect the caribou numbers strongly enough to be perceptible above the normal fluctuations caused by weather, insect cycles and many other factors. It hasn't yet: at 27,000, the Central Arctic herd is five times as large as it was in 1978.

But in a 1995 study Cameron and others reported data show-

CONSTRUCTION OF OIL FIELDS similar to the new Alpine site could begin in the Arctic refuge in about six years if Congress passes a bill now before it. On each field 60 or more wells could drain oil from up to six miles away.

PHILLIPS ALASKA, INC.

ing that a 20-pound drop in the weight of the mother could lower calf survival by 20 percent and fertility by 30 percent. Cameron also tracked down radio-tagged cows and found that those that summered among the oil fields bore 23 percent fewer calves on average than their counterparts east of the river. But a critical link in this logical chain is missing: evidence that caribou, pushed off their preferred forage, don't get enough to eat.

Caribou in ANWR might suffer more than the Central Arctic herd has, because almost five times as many animals there forage in an area one fifth the size of the plain surrounding Prudhoe and Kuparuk. With fewer options, a larger fraction of the caribou cows may lose weight and bear fewer young. Oil fields could push more of them into the foothills, where calves are most likely to fall prey to eagles, wolves or bears. Griffith and his colleagues recently combined satellite imagery with caribou-calving and grizzly-bear-tracking data from the 1002 Area into a computer model. It predicts that pushing the caribou calving concentration toward the foothills would reduce annual calf survival by 14 percent on average, Griffith says.

And Fish and Wildlife Service biologist Patricia Reynolds, who monitors the 250 muskoxen that live within the 1002 Area, points out that those animals survive the brutal winters on the plain primarily by moving little and conserving stored fat. If oil workers mine gravel from the riverbanks where they stand, the muskoxen will bolt, upsetting a precariously balanced energy budget and jeopardizing their young.

On the other hand, if the drill pads are served by short airstrips rather than long networks of roads, the caribou may fear them less and suffer little displacement. Wells no longer need be directly above the reservoir, so drill pads could be placed to avoid the most nutritious cottongrass patches. Many of the muskoxen wear radio collars, so pains could be taken to avoid them.

All things considered, the wildlife would probably cope. The question is, could we? Science itself may have a vested interest in thwarting S. 389, suggests John W. Schoen, senior scientist with the Audubon Society in Anchorage. "If global climate is changing, its effects will be most magnified in northern latitudes, in places like the Arctic refuge," he argues. "How are we going to measure these subtle changes and sort out which are due to industrial development versus which are due to global climate change? One way is to protect some areas as experimental controls. The Arctic refuge would certainly serve as such a laboratory—if it remains intact."

In fact, the 1002 Area is already the centerpiece of a long and revealing experiment—a social and political experiment that may at last be approaching its conclusion. How the question is settled will reveal something about the American public's priorities, its patience, and its tolerance for risk. SA

MORE TO EXPLORE

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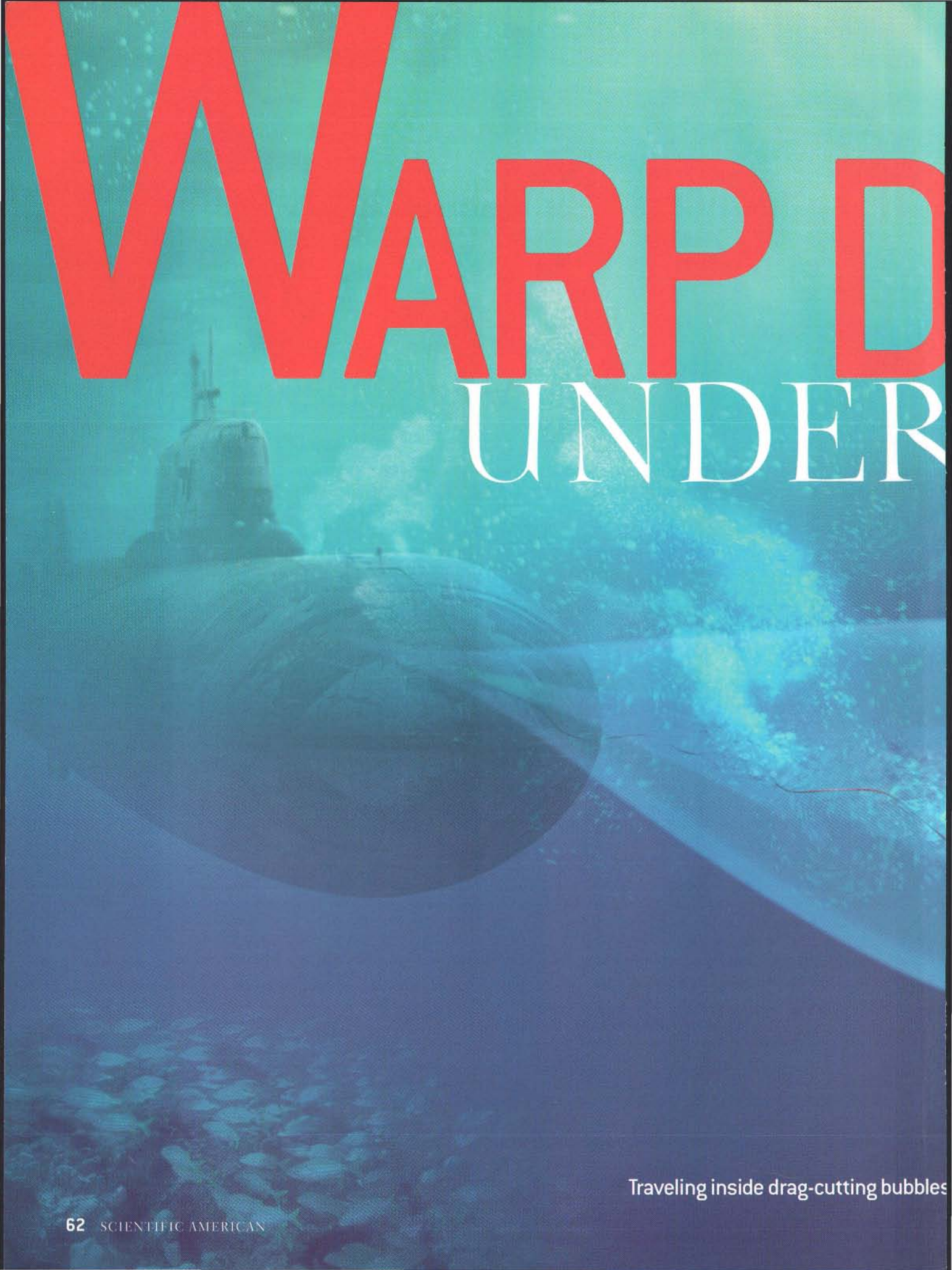
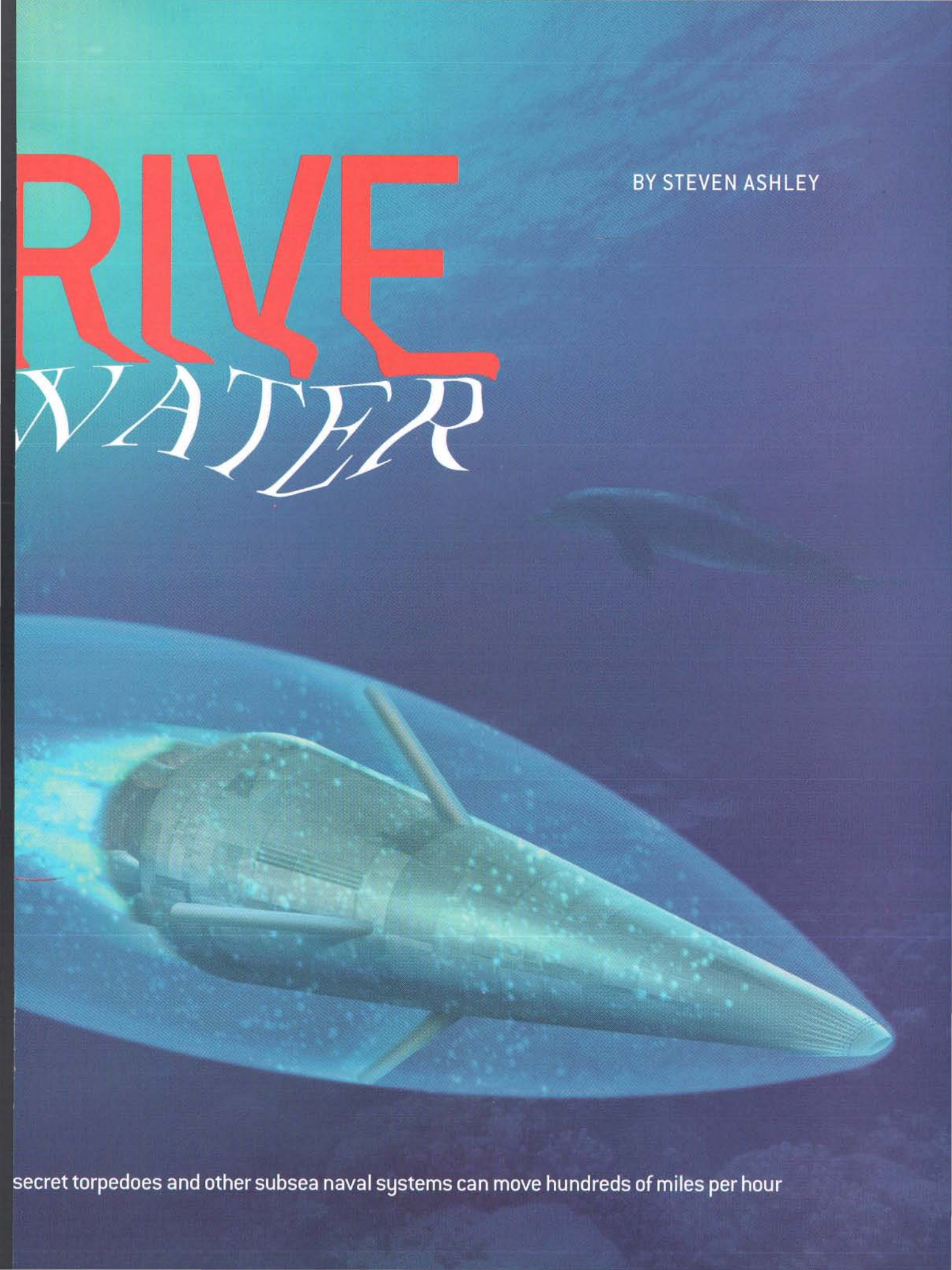


WARP D
UNDER

Traveling inside drag-cutting bubbles

RIVE WATER

BY STEVEN ASHLEY



secret torpedoes and other subsea naval systems can move hundreds of miles per hour

When the Russian submarine K-141 Kursk *sank last August, rumors rapidly arose that the mysterious blasts that sent the big boat to the bottom of the Barents Sea were connected to the testing of an ultrahigh-speed torpedo. Several months earlier, when American businessman*

Edmond Pope was arrested in Moscow on charges of espionage, it was said that he had been trying to buy the plans for an ultrahigh-speed torpedo. Although the details surrounding both the tragic naval accident and the celebrated spy case remain unsettled, evidence does suggest that both incidents revolved around an amazing and little-reported technology that allows naval weapons and vessels to travel submerged at hundreds of miles per hour—in some cases, faster than the speed of sound in water. The swiftest traditional undersea technologies, in contrast, are limited to a maximum of about 80 mph.

Of late, it has become increasingly apparent that the world's major naval powers are developing the means to build entire arsenals of innovative underwater weapons and armadas of undersea watercraft able to operate at unprecedented speeds. This high-velocity capability—a kind of "warp drive" for water—is based on the physical phenomenon of supercavitation. This fluid-mechanical effect occurs when bubbles of water vapor form in the lee of bodies submerged in fast-moving water flows. The trick is to surround an object or vessel with a renewable envelope of gas so that the liquid wets very little of the body's surface, thereby drastically reducing the viscous drag. Supercavitating systems could mean a quantum leap in naval warfare that is analogous in some ways to the move from prop planes to jets or even to rockets and missiles.

Although current funding levels for supercavitation research are said to be modest (around $50 million in the U.S., for example), the list of potential supercavitating weapons and naval vessels is extensive and altogether startling. It includes high-speed underwater bullets aimed at mines, homing torpedoes, boats—even low-flying aircraft and helicopters—from submerged gun-pods that look like the turrets on World War II–era aerial bombers. Other possibilities include high-velocity antiship and antitorpedo torpedoes and "midrange unguided engagement breakers," which are larger weapons intended to force an end to a conflict between two submarines. Also envisioned are small, superfast surface craft as well as nuclear-capable subsea missiles designed to neutralize entire aircraft-carrier battle groups.

Some naval experts believe that supercavitating systems could alter the nature of undersea warfare, changing stealthy cat-and-mouse stalking contests between large submarines into something resembling aerial combat, featuring noisy high-speed dogfights among small, short-range "subfighters" shooting underwater bullets at one another after having been launched from giant "subcarriers."

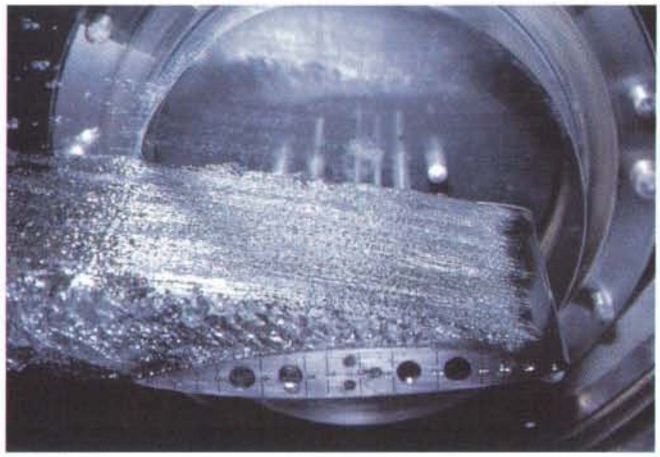
Overview/*Swift Subsea Weapons*

- The world's major navies are developing arsenals of innovative high-speed undersea weapons and vessels based on the phenomenon of supercavitation, which allows them to reduce hydrodynamic drag by traveling inside self-generated bubbles of water vapor and gas.
- The Russian navy has already deployed a rocket-powered supercavitating torpedo—the Shkval (Squall)—that is said to go 230 miles per hour. Cash-strapped Russia is looking to sell an improved version of the weapon to other countries. The Shkval has already turned up in France, China and Iran.
- The extensive list of potential supercavitating naval weapons includes short-range underwater projectiles to destroy mines and incoming torpedoes, high-velocity torpedoes, large subsea missiles for destroying entire battle groups, small ultrahigh-speed surface ships, and perhaps even supercavitating submarines. A long-range, multistage strategic torpedo/missile tipped with nuclear warheads that could possibly defeat "Star Wars" defenses has also been envisioned.

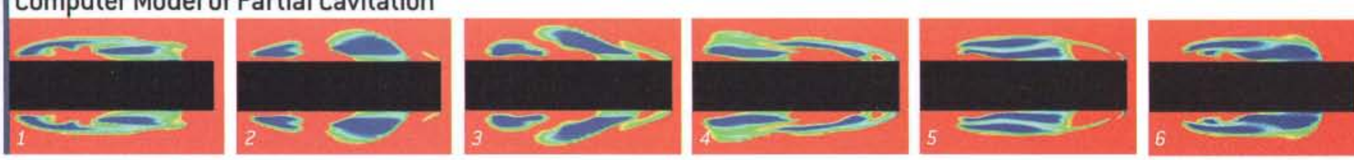
PHILIP HOWE [*preceding page*]

How Supercavitation *Works*

WATER FLOWING RAPIDLY around an object causes the fluid pressure to fall. At speeds beyond about 50 meters per second, the pressure drops sufficiently to allow the water to dissociate into water vapor, forming a gas bubble behind the object (cavitation). When the gas bubble fully encloses the object, it is called supercavitation. Slender axisymmetric bodies, such as the high-speed Russian Shkval torpedo (*top*) create long ellipsoidal supercavities. The middle photograph depicts a foil in a water tunnel at the University of Grenoble in France. High-velocity fluid flow (*from the right*) produces supercavitation above the top surface. Computational fluid dynamics modeling (*below*) performed at ARL/Penn State shows partial cavitation caused by flow over a blunt forebody and what specialists call "cavity shedding" phenomena (*liquid is red; vapor is blue*).



Computer Model of Partial Cavitation



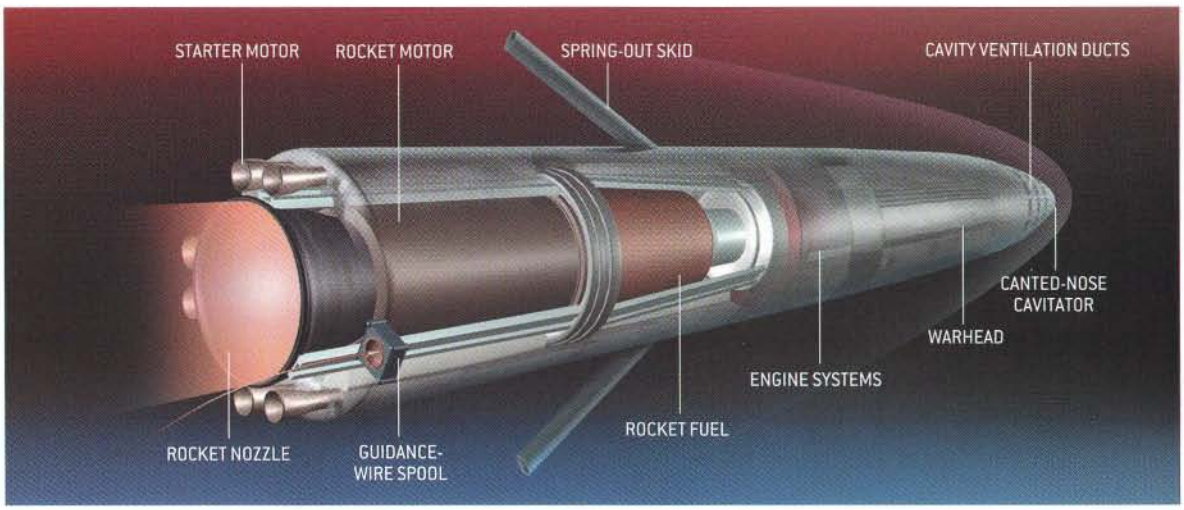
Other experts point to the possibility of fielding long-distance, multistage supercavitating torpedoes/missiles fitted with nuclear warheads ("long-range guided preemptive weapons") that could prove to be a relatively cheap and effective counter to future "Star Wars" missile defense systems. These devices could dash in from many miles out at sea entirely underwater, pop out of coastal waters close to their targets, and drop their lethal payloads before any aerial or space-based defenses could react.

Surprisingly, we now know of at least one supercavitating weapon that has existed for many years. In 1977, after more than a decade of research and development, the Soviet navy secretly introduced a rocket-powered torpedo called the Shkval (Squall) that can "fly" through water at 100 meters per second (about 230 miles per hour) or more inside a self-generated gas cavity. Although this nuclear-tipped underwater missile is in some ways a bit crude and less than entirely effective, news of it in the early 1990s forced the Western military powers to take notice of supercavitating technology.

There's no doubt that many significant challenges beyond the merely technical would have to be addressed before any of these next-generation technologies achieves reality. Environmental concerns as well as navigation issues would have to be considered, for instance. Probably the biggest barrier to advancement would be finding sufficient capital to develop and build supercavitating marine systems. Nevertheless, history shows that military technology often finds financial support when money for other purposes is scarce.

"Since very few of these things have been built so far, in many ways we're at a stage similar to that of the airplane right after the Wright brothers first flew," says Robert Kuklinski, an engineer and hydrodynamics research scientist at the Naval Undersea Warfare Center (NUWC) Division Newport in Rhode Island, the lead

LEGI/img (*middle*); ARL/PENN STATE AND RTO/NATO (*bottom*)



RUSSIAN SQUALL
The Russian Shkval torpedo (*in cutaway*) is thought to feature a flat disk cavitator at the nose to create a partial cavity that is expanded into a supercavity by gases injected from forward-mounted vents. Small starter rockets get the weapon moving until a cavity is formed, whereupon the large central rocket kicks in.

U.S. Navy laboratory investigating supercavitating systems. "But unlike then, we know a lot more about the underlying physics and technology than those early aerial pioneers did."

Supercavitation Fundamentals

PROPELLING A BODY through water takes considerable effort, as every swimmer knows. Speeding up the pace makes the task even harder because skin friction rises with increased velocity. Swimming laps entirely underwater is even more difficult, as water produces 1,000 times more drag resistance than air does.

Naval architects and marine engineers vie constantly with these age-old problems when they streamline the shapes of their hull designs to minimize the frictional drag of water and fit their ships with powerful engines to drive them through the waves. It can come as a shock, therefore, to find out that scientists and engineers have come up with a new way to overcome viscous drag resistance and to move through water at high velocities. In general, the idea is to minimize the amount of wetted surface on the body by enclosing it in a low-density gas bubble.

"When a fluid moves rapidly around a body, the pressure in the flow drops, particularly at trailing edges of the body," explains Marshall P. Tulin, director of the Ocean Engineering Laboratory at the University of California at Santa Barbara and a pioneer in the theory of supercavitating flows. "As velocity increases, a point is reached at which the pressure in the flow equals the vapor pressure of water, whereupon the fluid undergoes a phase change and becomes a gas: water vapor." In other words, with insufficient pressure to hold them together, the liquid water molecules dissociate into a gas.

"Under certain circumstances, especially at sharp edges, the flow can include attached cavities of approximately constant pressure filled with water vapor and air trailing behind. This is what we call natural cavitation," Tulin says. "The cavity takes on the shape necessary to conserve the constant pressure condition on its boundary and is determined by the body creating it, the cavity pressure and the force of gravity," he explains. Naval architects and marine engineers typically try to avoid cavitation because it can distort water flow to rob pumps, turbines, hydrofoils and propellers of operational efficiency. It can also lead to violent shock waves (from rapid bubble collapse), which cause pitting and erosion of metal surfaces.

Supercavitation is an extreme version of cavitation in which a single bubble is formed that envelops the moving object almost completely. At velocities over about 50 meters per second, (typically) blunt-nosed cavitators and prow-mounted gas-injection systems produce these low-density gas pockets (what specialists call supercavities). With slender, axisymmetric bodies, supercavities take the shape of elongated ellipsoids beginning at the forebody and trailing behind, with the length dependent on the speed of the body.

The resulting elliptically shaped cavities soon close up under the pressure of the surrounding water, an area characterized by complex, unsteady flows. Most of the difficulties in mathematically modeling supercavitating flows arise when considering what Tulin calls "the mess at the rear" of cavities, known as the collapse or closure region. In reality, the pressures inside gas cavities are not constant, which leads to many of the analysis problems, he says.

However they're modeled, as long as the water touches only the cavitator, supercavitating devices can scoot along the interiors of the lengthy gas bubbles with minimal drag.

CAVITATORS
Different nose geometries can be used to create supercavities—flat disks, cones, "gear-shaped" plates and cones (*top* and *middle*), faceted concavities and cavitators with inscribed cones that move in and out like the tips of ballpoint pens (*bottom*).

U.S. Supercavitation Efforts

ALTHOUGH SUPERCAVITATION research in this country focused on high-speed propeller and hydrofoil

The U.S. Navy opted to pursue stealth rather than HIGH VELOCITY. With no supercavitating weapons, the U.S. Navy is now trying to CATCH UP with the Russian navy.

development in the 1950s, the U.S. Navy subsequently opted to pursue other underwater technologies, particularly those related to stealth operations, rather than high-velocity capabilities. As a result, experts say, the U.S. Navy currently has no supercavitating weapons and is now trying to catch up with the Russian navy.

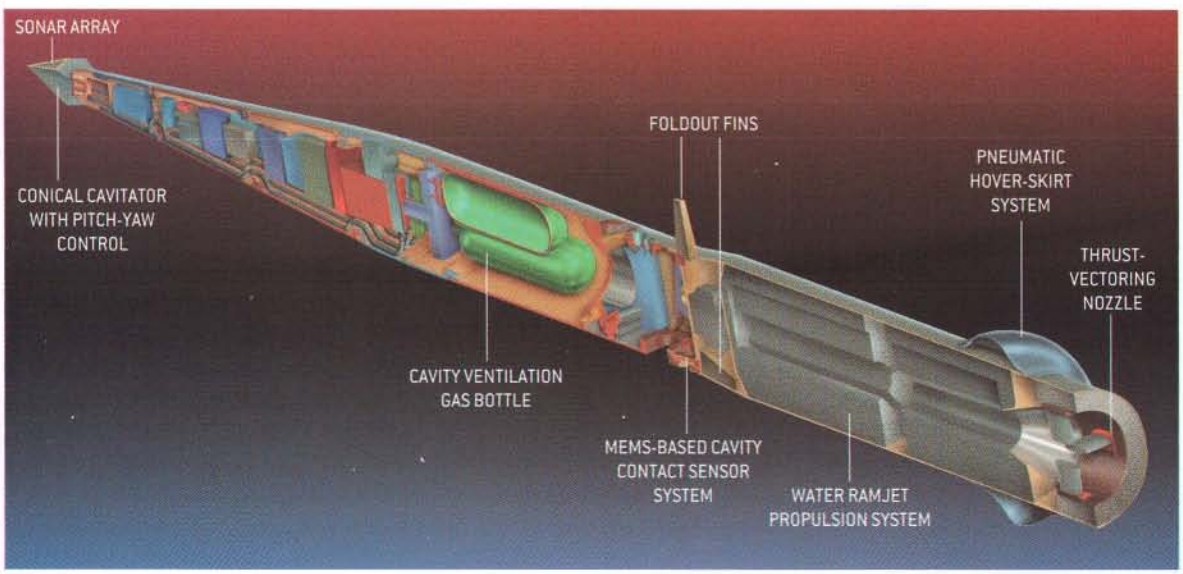
Supercavitating weapons work in the U.S. is being directed by the Office of Naval Research (ONR) in Arlington, Va. In general, the ONR's efforts are aimed at developing two classes of supercavitating technologies: projectiles and torpedoes.

The first class of weapons is represented by RAMICS (for Rapid Airborne Mine Clearance System), a soon-to-be-requisitioned helicopter-borne weapon that destroys surface and near-surface marine mines by firing supercavitating rounds at them. The 20-millimeter flat-nosed projectiles, which are designed to travel stably through both air and water, are shot from a modified rapid-fire gun with advanced targeting assistance. (The fielded RAMICS projectiles are expected to be enlarged to 30-millimeter caliber.) Raytheon Naval & Maritime Integrated Systems in Portsmouth, R.I., is the chief contractor for RAMICS, and engineers at C Tech Defense Corporation in Port Angeles, Wash., developed the projectiles [*see box on page 69*]. The U.S. Navy is also considering deploying a surface ship–borne, deck-mounted RAMICS-type close-in weapons system that could destroy deadly wake-following torpedoes.

The next step in supercavitating projectile technology will be an entirely subsurface gun system using Adaptable High-Speed Undersea Munitions (AHSUM). These would take the form of supercavitating "kinetic-kill" bullets that are fired from guns in streamlined turrets fitted to the submerged hulls of submarines, surface ships or towed mine-countermeasure sleds. The sonar-directed AHSUM system is hoped to be the underwater equivalent of the U.S. Navy's Phalanx weapons system, a radar-controlled rapid-fire gun that protects surface vessels from incoming cruise missiles.

The other supercavitating technology of interest to the ONR is a torpedo with a maximum velocity of about 200 knots. Substantial technical and system challenges stand in the way of the desired torpedo in the areas of launching, hydrodynamics, acoustics, guidance and control, and propulsion, to name a few, according to ONR program manager Kam Ng. NUWC Newport is doing the applied research and some of the basic research work as well. The effort is supported by the Applied Research Laboratory at Pennsylvania State University (ARL/Penn State), the University of Florida, Anteon Corporation and Lockheed Martin.

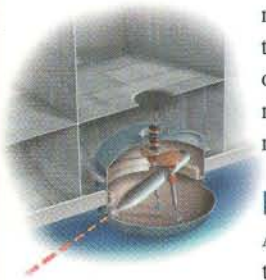
With regard to the computational fluid dynamics (CFD) work on the torpedo being done at ARL/Penn State, "we're trying to simulate the conditions in which the torpedo would operate, which is the so-called two-phase flow regime where there's both water and gas,"



PROTOTYPE WEAPON A future supercavitating torpedo based on U.S. Navy design concepts could feature a range of innovative cavitator, sensing, control and propulsion technologies.

Ng says. "We want to know what the water is doing, what the gas cavity is like, and how we make sure the gas cavity encloses the body at all times. Remember, once the cavity is disrupted, the wetted surface increases and the speed is going to drop off very quickly.

"So far the CFD is doing a fairly good job, but it's not yet to the point that we're happy with it," he continues. "It's both a matter of computational issues and our fundamental understanding of the physics. This is not a Newtonian fluid we're working with here; it's much more complex than a single-phase flow."



SUBSEA GUNS

The U.S. Navy is developing underwater launchers for rotating gun turrets that would be fitted below the waterline to fire "kinetic-kill" projectiles at mines, obstacles, surface craft, homing torpedoes—even low-flying airplanes and helicopters.

Profile of a Supercavitating Torpedo

AS THE FOREMOST existing example of a supercavitating device, the Russian Shkval underwater missile is ideal for the purpose of illuminating the basic parts of a first-generation design. The torpedo, which is reportedly 27 feet long and weighs 5,940 pounds, is "really a big projectile with a rocket on the end," jokes Yuriy N. Savchenko, who directs the research group at the Ukrainian Institute of Hydromechanics in Kiev, where most of the fundamentals of supercavitating weapons technology were first developed.

In general, the weapon consists of a large cylindrical hull containing a solid-rocket motor that tapers to a cone enclosing the warhead. The wide aperture of a rocket nozzle protrudes from the center of the aft end encircled by eight small cylinders, which are said to be small starter rockets. These get the Shkval moving up to supercavitation speed, whereupon the main engine cuts in. Nestled between two of the starter motor nozzles is thought to be a spool of guidance wire that unravels as the torpedo makes its way through the water. The wire would allow submarine personnel to control the weapon's operation and warhead detonation.

Up front, things get a bit more speculative. Experts believe that the nose of the torpedo features what is likely to be a flat disk with a circular or perhaps elliptical shape. This is the all-important cavitator, which creates the gas cavity in which the craft moves. The cavitator disk will be tilted forward at the top, providing an "angle of attack" to generate the lift needed to support the forebody of the device. The cavitator's edge is apt to be sharp, which hydrodynamicists say creates the cleanest or least turbulent gas/water boundary, what they call a "glassy" cavity. Just aft of the cavitator sit several rings of ventilation ducts that inject rocket exhaust and steam into the cavitation bubble to enlarge it. About two thirds of the way back from the nose are four spring-out cylinders angled toward the stern. Although they loosely resemble fins, these spring-tensioned skids actually support the aft end of the torpedo by allowing it to bounce off the inner cavity surface. Western experts believe that the Shkval actually "precesses" slowly around the cavity's circumference, repeatedly ricocheting off the walls as it makes its way through the water.

The Shkval is considered to be somewhat unrefined

International *Supercavitation Research*

RUSSIA: Although Russia leads the world in supercavitating weapons technology based on its early and extensive work in the field, it is unclear exactly how much progress that country has made in recent years. A significant classified program on supercavitating weapons is reportedly ongoing at TsAGI, the renowned Central Aerohydrodynamic Institute in Zhukovsky, which is thought to have done much of the engineering work on the Shkval underwater missile. Western experts believe that Russian researchers were the first to attain fully submerged supersonic speeds through water. Some say that TsAGI engineers are investigating the possibility of developing supercavitating submarines as well.

UKRAINE: Much of the fundamental technology that underlies the Russian Shkval torpedo came out of the Ukrainian Institute of Hydromechanics in Kiev, which in Soviet times was directed by academician Georgy Logvinovich, one of the pioneers of supercavitation theory. That facility contains a sophisticated water-tank testing system in which wire-riding models are catapulted or jet-propelled through water while under close observation. Researchers at the Institute of Hydromechanics, who are known for their successful semianalytic mathematical approach and extensive testing work, have been trading information about supercavitating technology with their American counterparts since the fall of the Soviet Union.

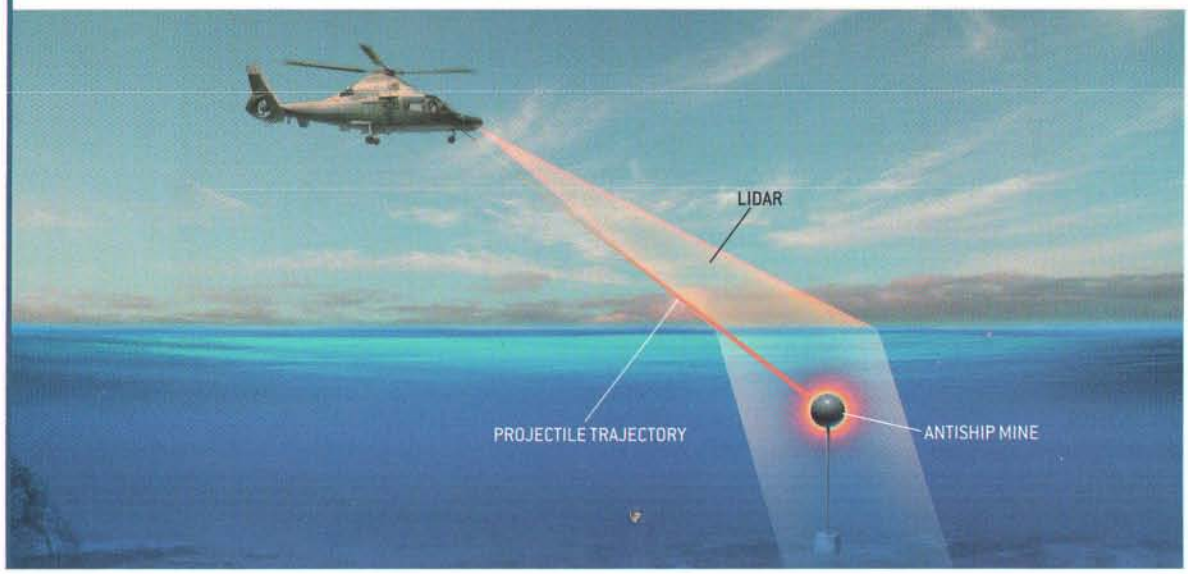
FRANCE: In the past decade, under the supervision of the Directorate of Research, Studies and Techniques (DRET), France has supported a program called Action Concertée Cavitation. Reliable sources report that the government is strongly, if covertly, pursuing supercavitating weaponry. For example, France has reportedly purchased several Shkvals from the Russians for evaluation. Tests of prototype air-launched antimine supercavitating projectiles are being performed at the French-German Research Institute of Saint-Louis.

GERMANY: The German Federal Office for Defense Technology and Procurement in Koblenz is cooperating with U.S. Navy researchers in a joint development program on new cavitator designs and the modeling of homing systems for torpedoes. Engineers have also completed initial development of a supercavitating torpedo prototype that is expected to begin trials soon in the U.S.

Neutralizing *Mines*

EVERYONE HAS SEEN action-movie heroes avoid fusillades of bullets by diving several feet underwater. The bullets ricochet away or expend their energy surprisingly rapidly as a result of drag and lateral hydrodynamic forces.

When the Office of Naval Research was asked to find a cost-effective way to stop thousand-dollar surface mines from damaging or destroying multimillion-dollar ships, they turned to supercavitating projectiles. The result was RAMICS—the Rapid Airborne Mine Clearance System, which is being developed for the U.S. Navy by a team led by Raytheon Naval & Maritime Integrated Systems in Portsmouth, R.I. Operating from helicopters, RAMICS will locate subsurface sea mines with an imaging blue-green lidar (light detection and ranging) system, calculate their exact position despite the bending of light by water refraction, and then shoot them with supercavitating rounds that travel stably in both air and water. The special projectiles contain charges that cause the deflagration, or moderated burning, of the mine's explosives.



ANTIMINE PROJECTILE

Supercavitating projectiles shot from above the ocean surface must fly stably in both air and water—a difficult engineering task. The RAMICS round (*partially visible*) was developed by C Tech Defense Corporation.

because it can travel only along a straight trajectory, but future supercavitating vehicles are being designed to maneuver through the water. Steering is possible through the use of cavity-piercing control surfaces such as fins, and thrust-vectoring systems, which are directional nozzles for jet exhaust. Extreme care must be taken to keep the body inside the cavity during turns, however, because should it stray from the cavity, the force of slamming into the surrounding wall of water would abruptly turn it into "a crushed Coke can," according to Ivan Kirschner, an engineer at Anteon's Engineering Technology Center in Mystic, Conn.

"Three-dimensional pitch and yaw maneuvers could also be accomplished by moving or rotating the nose cavitator in two planes simultaneously," Kirschner continues, "although such devices would be more complicated." Researchers have also considered using forward-actuated canards.

Supercavitating vehicles could be highly agile if the control surfaces were coordinated correctly, says NUWC's Kuklinsky. The idea is to skew the cavity to one side to create the desired side forces with an articulated nose cavitator or with control surfaces and then track the vehicle in it. If the fore and aft control systems operate in phase so that the "back end keeps up with what the front is doing, very fast turns can be accomplished," he notes.

Part of the solution to the control problem is to install a reliable, real-time feedback control loop that can keep abreast of cavity conditions in the rear of the craft and make the appropriate response to measured changes. As supercavitating systems travel unsupported inside low-density gas bubbles, their afterbodies often bang off the inside wall of cavities. Specialists call this the "tail-slap" phenomenon, which is regularly observed in high-speed test photography of supercavitating devices. The ONR has sponsored the development of a "tail-slap" sensor—a monitoring system based on microelectromechanical components that will track intermittent afterbody contact with the cavity.

An important point regarding future supercavitating vehicles is the fact that transitions from normal underwater travel into the supercavitating regime and back out again can be accomplished by artificially ventilating a partial cavity to maintain and expand it through the velocity transitions. Thus, a small natural cavity formed at the nose (at lower speeds) can be "blown up" into a large one that fully encloses the en-

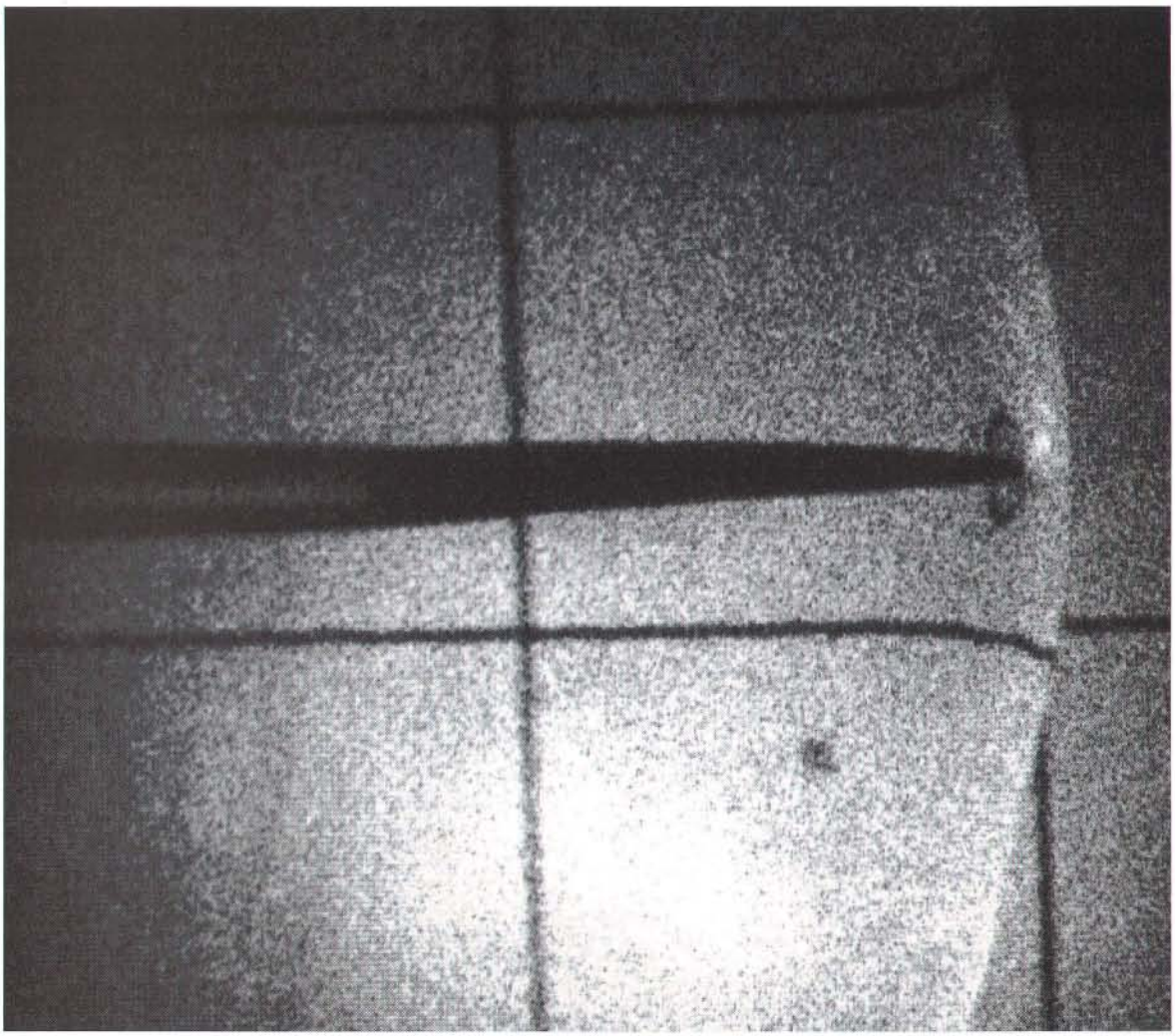
As there are NO KNOWN COUNTERMEASURES, to such a weapon, its deployment could have a significant effect on future maritime operations.

tire body. Conversely, braking maneuvers can be eased by augmenting the bubble with injection gases to maintain and then slowly reduce its size so as to gradually scrub speed. [*For more information on supercavitating systems, see "More to Explore," on opposite page.*]

Advanced Propulsion Systems

MOST EXISTING and anticipated autonomous supercavitating vehicles rely on rocket-type motors to generate the required thrust. But conventional rockets entail some serious drawbacks—limited range and declining thrust performance with the rise of pressure as depth increases. The first of these problems is being addressed with a new kind of high-energy-density powerplant technology; the second may be circumvented by using a special kind of supercavitating propeller screw technology.

"Getting up to supercavitation speeds requires a lot of power," says researcher Savchenko. "For maximum range with rockets, you need to burn high-energy-density fuels that provide the maximum specific impulse." He estimates that a typical solid-rocket motor can achieve a maximum range of several tens of kilometers and a top speed of perhaps 200 meters per second. After considering propulsion systems based on diesel engines, electric motors, atomic power plants, high-speed



SUPERSONIC BULLET In 1997 a research team at the Naval Undersea Warfare Center Division Newport in Rhode Island demonstrated the fully submerged launch of a supercavitating projectile with a muzzle velocity of 1,549 meters per second, which exceeds the speed of sound in water.

diesels, and gas turbines, Savchenko concluded that "only high-efficiency gas turbines and jet propulsion systems burning metal fuels (aluminum, magnesium or lithium) and using outboard water as both the fuel oxidizer and coolant of the combustion products have real potential for propelling supercavitating vehicles to high velocities."

Aluminum, which is relatively cheap, is the most energetic of these metal fuels, producing a reaction temperature of up to 10,600 degrees Celsius. "One can accelerate the reaction by fluidizing [melting] the metal and using water vapor," Savchenko explains. In one candidate power-plant design, the heat from the combustion chamber would be used to melt stored aluminum sheets at about 675 degrees C and to vaporize seawater as well. The resulting combustion products turn turbine-driven propeller screws.

This type of system has already been developed in Russia, according to media reports there. The U.S. also has experience with these kinds of systems. Researchers at Penn State's Applied Research Laboratory are operating an aluminum-burning "water ramjet" system, which was developed as an auxiliary power source for a naval surface ship.

In the novel American design, powdered aluminum feeds into a whirlpool of seawater occurring in what is called a vortex combustor. The rapid rotation scrapes the particles together, grinding off the inert aluminum oxide film that covers them, which initiates an intense exothermic reaction as the aluminum oxidizes. High-pressure steam from this combustion process expands out a rocket nozzle or drives a turbine that turns a propeller screw.

Tests have shown that prop screws offer the potential to boost thrust by 20 percent compared with that of rockets, although in theory it may be possible for screws to double available thrust, Savchenko says. Designs for a turbo-rotor propeller system with a single supercavitating "hull propeller," or a pair of counterrotating hull props that encircle the outer surface of the craft so they can reach the gas/water boundary, have been tested. He emphasizes, however, that "considerable work remains to be done on how the propeller and cavity must interact" before real progress can be made.

Fears for the Future

WHATEVER THE YEARS AHEAD may hold for supercavitating weapons, they have already exerted a strong influence on military and intelligence communities around the world. Indeed, they seem to have spurred some reevaluation of naval strategy.

For example, when news of the Shkval's existence emerged, a debate soon ensued regarding its purpose. Some Western intelligence sources say that the Shkval had been developed to allow the noisy, low-tech diesel subs of the then Soviet Union to respond if suddenly fired on by ultraquiet American submarines lurking nearby. On hearing the screws of the incoming conventional torpedo, the Shkval would be launched to force an attacker to evade and thereby perhaps to cut the incoming torpedo's guidance wire. In effect, they say, the Shkval is a sub killer, particularly if it is fitted with a tactical nuclear warhead.

Other informed sources claim that the missile is in fact an offensive weapon designed to explode a higher-yield nuclear charge amid a carrier battle group, thereby taking out the entire armada. During a nuclear war, it could even be directed at a port or coastal land target.

"As there are no known countermeasures to such a weapon," states David Miller's April 1995 article "Supercavitation: Going to War in a Bubble," in *Jane's Intelligence Review*, "its deployment could have a significant effect on future maritime operations, both surface and subsurface, and could put Western naval forces at a considerable disadvantage."

In recent years, cash-strapped Russia has openly offered the Shkval for sale at international arms shows in Abu Dhabi and Athens, a development that causes grave concern in the Pentagon. Well-placed sources say that several Shkvals have been sold to Iran, for example.

Of equal worry is an August 1998 report that China purchased around 40 Shkval torpedoes from Kazakhstan, raising the possibility that Beijing could threaten American naval forces in a future confrontation in the Taiwan Strait. News from China (reportedly confirmed by U.S. Navy sources) that a Chinese submarine officer was on board the sunken *Kursk* has also raised alarms. He was there, they say, to observe the test of a new version of the Shkval.

U.S. intelligence has received several indications that the Russians were working on an advanced, much longer-range Shkval. For example, Russia's Itar-Tass news agency reported in February 1998 that tests of a "modernized" Shkval were scheduled by Russia's Pacific Fleet for that spring.

The *Kursk* incident, the Pope trial and the ambiguity surrounding both reinforce the fact that the end of the cold war has in no way halted the clandestine arms competition to secure an edge in any future conflict. Clearly, the secret storm over the Shkval rages on. SA

UNDERSEA MISSILES

The U.S. Navy is considering design concepts for large, extended-range supercavitating weapons. On the left is a "midrange unguided engagement breaker"; on the right is a "long-range guided preemptive weapon."

MORE TO EXPLORE

More Stories, Photographs and Images: **www.sciam.com/2001/0501issue/0501ashley/**

Other Sources:

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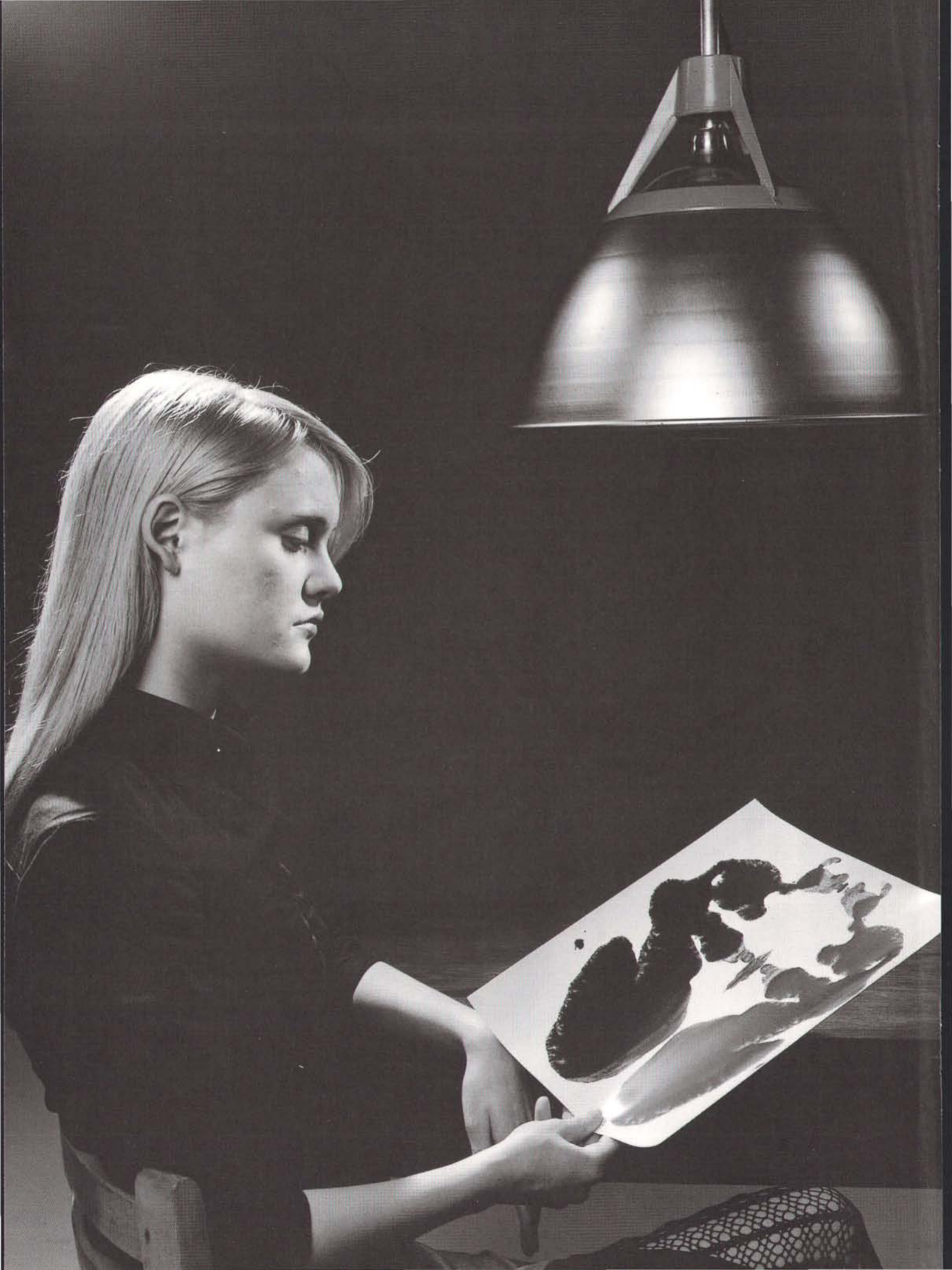
Acknowledgment: NATO RTO AVT/VKI Special Course on Supercavitating Flows, February 2001, von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium



BY SCOTT O. LILIENFELD, JAMES M. WOOD AND HOWARD N. GARB

What's Wrong with This PICTURE?

PHOTOGRAPHS BY JELLE WAGENAAR

PSYCHOLOGISTS OFTEN USE THE FAMOUS RORSCHACH INKBLOT TEST AND RELATED TOOLS TO ASSESS PERSONALITY AND MENTAL ILLNESS. BUT RESEARCH SAYS THE INSTRUMENTS ARE FREQUENTLY INEFFECTIVE FOR THOSE PURPOSES

What if you were asked to describe images

you saw in an inkblot or to invent a story for an ambiguous illustration—say, of a middle-aged man looking away from a woman who was grabbing his arm? To comply, you would draw on your own emotions, experiences, memories and imagination. You would, in short, project yourself into the images. Once you did that, many practicing psychologists would assert, trained evaluators could mine your musings to reach conclusions about your personality traits, unconscious needs and overall mental health.

But how correct would they be? The answer is important because psychologists frequently apply such "projective" instruments (presenting people with ambiguous images, words or objects) as components of mental assessments, and because the outcomes can profoundly affect the lives of the respondents. The tools often serve, for instance, as aids in diagnosing mental illness, in predicting whether convicts are likely to become violent after being paroled, in evaluating the mental stability of parents engaged in custody battles, and in discerning whether children have been sexually molested.

We recently reviewed a large body of research into how well projective methods work, concentrating on three of the most extensively used and best-studied instruments. Overall our findings are unsettling.

Butterflies or Bison?

THE FAMOUS RORSCHACH inkblot test—which asks people to describe what they see in a series of 10 inkblots—is by far the most popular of the projective methods, given to hundreds of thousands, or perhaps millions, of people every year. The research discussed below refers to the modern, rehabilitated version, not to the original construction, introduced in the 1920s by Swiss psychiatrist Hermann Rorschach.

The initial tool came under severe attack in the 1950s and 1960s, in part because it lacked standardized procedures and a set of norms (averaged results from the general population). Standardization is important because seemingly trivial differences in the way an instrument is administered can affect a person's responses to it. Norms provide a reference point for determining when someone's responses fall outside an acceptable range.

In the 1970s John E. Exner, Jr., then at Long Island University, ostensibly corrected those problems in the early Rorschach test by introducing what he called the Comprehensive System. This set of instructions established detailed rules for delivering the inkblot exam and for interpreting the responses, and it provided norms for children and adults.

In spite of the Comprehensive System's current popularity, it generally falls short on two crucial criteria that were also problematic for the original Rorschach: scoring reliability and validity. A tool possessing scoring reliability yields similar results regardless of who grades and tabulates the responses. A valid technique measures what it aims to measure: its results are consistent with those produced by other trustworthy instruments or are able to predict behavior, or both.

To understand the Rorschach's scoring reliability defects, it helps to know something about how reactions to the inkblots are interpreted. First, a psychologist rates the collected reactions on more than 100 characteristics, or variables. The evaluator, for instance, records whether the person looked at whole blots or just parts, notes whether the detected images were unusual or typical of most test takers, and indicates which aspects of the

inky swirls (such as form or color) most determined what the respondent reported seeing.

Then he or she compiles the findings into a psychological profile of the individual. As part of that interpretive process, psychologists might conclude that focusing on minor details (such as stray splotches) in the blots, instead of on whole images, signals obsessiveness in a patient and that seeing things in the white spaces within the larger blots, instead of in the inked areas, reveals a negative, contrary streak.

For the scoring of any variable to be considered highly reliable, two different assessors should be very likely to produce similar ratings when examining any given person's responses. Recent investigations demonstrate, however, that strong agreement is achieved for only about half the characteristics examined by those who score Rorschach responses; evaluators might well come up with quite different ratings for the remaining variables.

Equally troubling, analyses of the Rorschach's validity indicate that it is poorly equipped to identify most psychiatric conditions—with the notable exceptions of schizophrenia and other disturbances marked by disordered thoughts, such as bipolar disorder (manic-depression). Despite claims by some Rorschach proponents, the method does not consistently detect depression, anxiety disorders or psychopathic personality (a condition characterized by dishonesty, callousness and lack of guilt).

Moreover, although psychologists frequently administer the Rorschach to assess propensities toward violence, impulsiveness and criminal behavior, most research suggests it is not valid for these purposes either. Similarly, no compelling evidence supports its use for detecting sexual abuse in children.

Other problems have surfaced as well. Some evidence suggests that the Rorschach norms meant to distinguish mental health from mental illness are unrepresentative of the U.S. population and mistakenly make many adults and children seem maladjusted. For instance, in a 1999 study of 123 adult volunteers at a California blood bank, one in six had scores supposedly indicative of schizophrenia.

The inkblot results may be even more misleading for minorities. Several investigations have shown that scores for African-Americans, Native Americans, Native Alaskans, Hispanics, and Central and South Americans differ markedly from the norms. Together the collected research raises serious doubts about the use of the Rorschach inkblots in the psychotherapy office and in the courtroom.

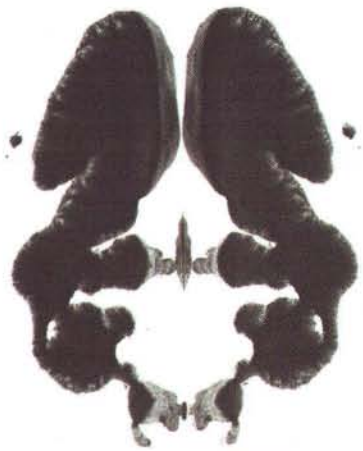
Doubts about TAT

ANOTHER PROJECTIVE TOOL—the Thematic Apperception Test (TAT)—may be as problematic as the Rorschach. This method asks respondents to formulate a story based on ambiguous scenes in drawings on cards. Among the 31 cards available to psychologists are ones depicting a boy contemplating a violin, a distraught woman clutching an open door, and the man and woman who were mentioned at the start of this article. One card, the epitome of ambiguity, is totally blank.

The TAT has been called "a clinician's delight and a statistician's nightmare," in part because its administration is usually not standardized: different clinicians present different numbers and selections of cards to respondents. Also, most clinicians interpret people's stories intuitively instead of following a well-tested scoring procedure. Indeed, a recent survey of nearly 100 North

THE AUTHORS

SCOTT O. LILIENFELD, JAMES M. WOOD and HOWARD N. GARB all conduct research on psychological assessment tools and recently collaborated on an extensive review of research into projective instruments that was published by the American Psychological Society (see "More to Explore," on page 79). Lilienfeld and Wood are associate professors in the departments of psychology at Emory University and the University of Texas at El Paso, respectively. Garb is a clinical psychologist at the Pittsburgh Veterans Administration Health Care System and the University of Pittsburgh and author of the book *Studying the Clinician: Judgment Research and Psychological Assessment*.



RORSCHACH TEST

Wasted Ink?

"It looks like two dinosaurs with huge heads and tiny bodies. They're moving away from each other but looking back. The black blob in the middle reminds me of a spaceship."

Once deemed an "x-ray of the mind," the Rorschach inkblot test remains the most famous—and infamous—projective psychological technique. An examiner hands 10 symmetrical inkblots one at a time in a set order to a viewer, who says what each blot resembles. Five blots contain color; five are black and gray. Respondents can rotate the images. The one above is an inverted version of an Andy Warhol rendering; the actual Rorschach blots cannot be published.

Responses to the inkblots purportedly reveal aspects of a person's personality and mental health. Advocates believe, for instance, that references to moving animals—such as the dinosaurs mentioned above—often indicate impulsiveness, whereas allusions to a blot's "blackness"—as in the spaceship—often indicate depression.

Swiss psychiatrist Hermann Rorschach probably got the idea of showing inkblots from a European parlor game. The test debuted in 1921 and reached high status by 1945. But a critical backlash began taking shape in the 1950s, as researchers found that psychologists often interpreted the same responses differently and that particular responses did not correlate well with specific mental illnesses or personality traits.

Today the Comprehensive System, meant to remedy those weaknesses, is widely used to score and interpret Rorschach responses. But it has been criticized on similar grounds. Moreover, several recent findings indicate that the Comprehensive System incorrectly labels many normal respondents as pathological.

American psychologists practicing in juvenile and family courts discovered that only 3 percent relied on a standardized TAT scoring system. Unfortunately, some evidence suggests that clinicians who interpret the TAT in an intuitive way are likely to overdiagnose psychological disturbance.

Many standardized scoring systems are available for the TAT, but some of the more popular ones display weak "test-retest" reliability: they tend to yield inconsistent scores from one picture-viewing session to the next. Their validity is frequently questionable as well; studies that find positive results are often contradicted by other investigations. For example, several scoring systems have proved unable to differentiate normal individuals from those who are psychotic or depressed.

A few standardized scoring systems for the TAT do appear to do a good job of discerning certain aspects of personality—notably the need to achieve and a person's perceptions of others (a property called "object relations"). But many times individuals who display a high need to achieve do not score well on measures of actual achievement, so the ability of that variable to predict a person's behavior may be limited. These scoring systems currently lack norms and so are

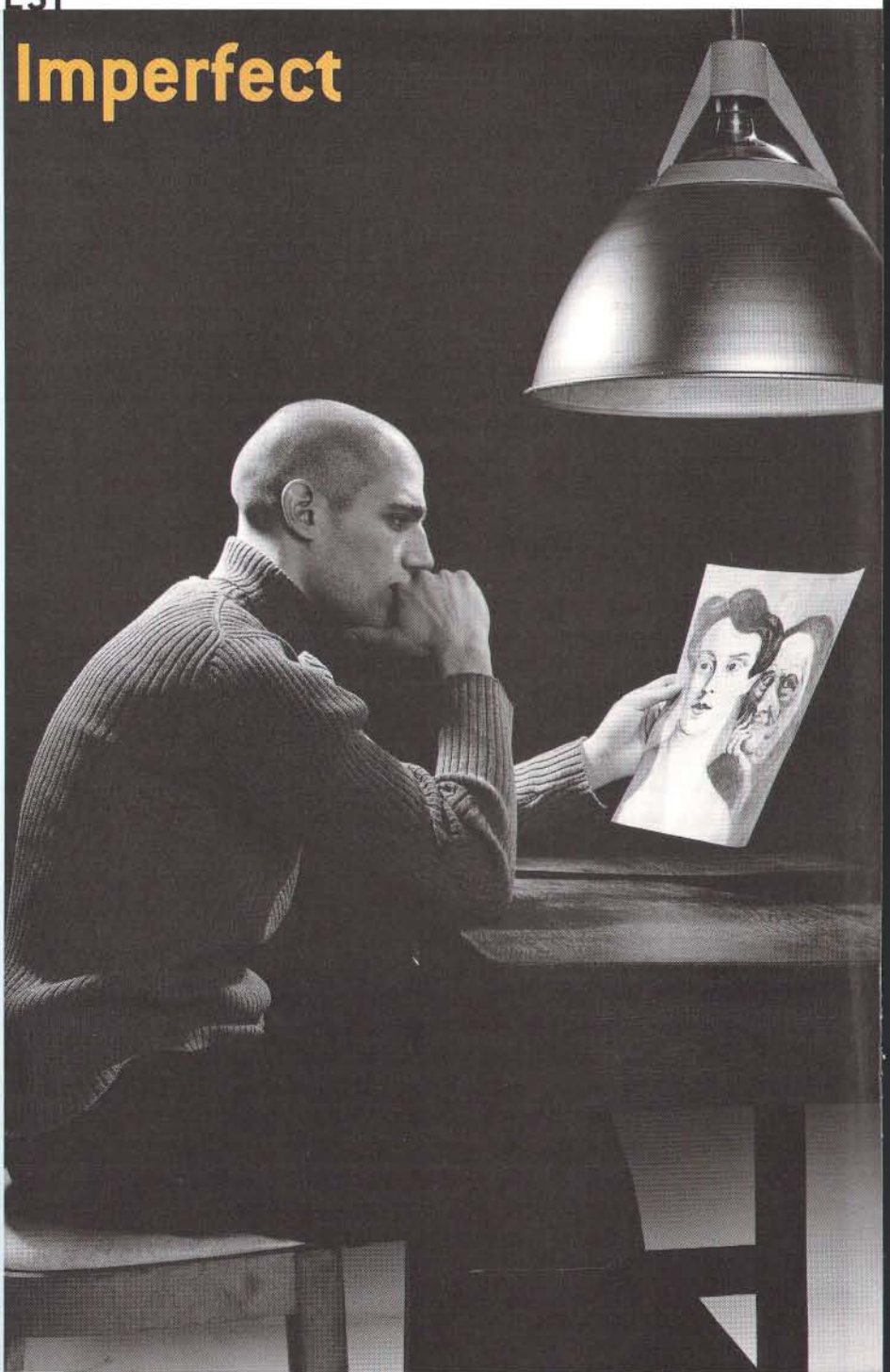
THEMATIC APPERCEPTION TEST

Picture Imperfect

The Thematic Apperception Test (TAT), created by Harvard University psychiatrist Henry A. Murray and his student Christiana Morgan in the 1930s, is among the most commonly used projective measures. Examiners present individuals with a subset (typically five to 12) of 31 cards displaying pictures of ambiguous situations, mostly featuring people. Respondents then construct a story about each picture, describing the events that are occurring, what led up to them, what the characters are thinking and feeling, and what will happen later. Many variations of the TAT are in use, such as the Children's Apperception Test, featuring animals interacting in ambiguous situations, and the Blacky Test, featuring the adventures of a black dog and its family.

Psychologists have several ways of interpreting responses to the TAT. One promising approach—developed by Boston University psychologist Drew Westen—relies on a specific scoring system to assess people's perceptions of others ("object relations"). According to that approach, if someone wove a story about an older woman plotting against a younger person in response to the image visible in the photograph at the right, the story would imply that the respondent tends to see malevolence in others—but only if similar themes turned up in stories told about other cards.

Surveys show, however, that most practitioners do not use systematic scoring systems to interpret TAT stories, relying instead on their intuitions. Unfortunately, research indicates that such "impressionistic" interpretations of the TAT are of doubtful validity and may make the TAT a projective exercise for both examiner and examinee.



not yet ready for application outside of research settings, but they merit further investigation.

Faults in the Figures

IN CONTRAST TO THE RORSCHACH and the TAT, which elicit reactions to existing images, a third projective approach asks the people being evaluated to draw the pictures. A number of these instruments, such as the frequently applied Draw-a-Person Test, have examinees depict a human being; others have them draw houses or trees as well. Clinicians commonly interpret the sketches by relating specific "signs"—such as features of the body or clothing—to facets of personality or to particular psychological disorders. They might associate large eyes with paranoia, long ties with sexual aggression, missing facial features with depression, and so on.

As is true of the other methods, the research on drawing instruments gives reason for serious concern. In some studies, raters agree well on scoring, yet in others the agreement is poor. What is worse, no strong evidence supports the validity of the sign approach to interpretation; in other words, clinicians apparently have no grounds for linking specific signs to particular personality traits or psychiatric diagnoses. Nor is there consistent evidence thats signs purportedly linked to child sexual abuse (such as tongues or genitalia) actually reveal a history of molestation. The only positive result found repeatedly is that, as a group, people who draw human figures poorly have somewhat elevated rates of psychological disorders. On the other hand, studies show that clinicians are likely to attribute mental illness to many normal individuals who lack artistic ability.

Certain proponents argue that sign approaches can be valid in the hands of seasoned experts. Yet one group of researchers reported that experts who administered the Draw-a-Person Test were

OTHER PROJECTIVE TOOLS

What's the Score?

Psychologists have dozens of projective methods to choose from beyond the Rorschach Test, the TAT and figure drawings. As the sampling below indicates, some stand up well to the scrutiny of research, but many do not.

Hand Test

Subjects say what hands pictured in various positions might be doing. This method is used to assess aggression, anxiety and other personality traits, but it has not been well studied.

Handwriting Analysis (Graphology)

Interpreters rely on specific "signs" in a person's handwriting to assess personality characteristics. Though useless, the method is still used to screen prospective employees.

Lüscher Color Test

People rank colored cards in order of preference to reveal personality traits. Most studies find the technique to lack merit.

Play with Anatomically Correct Dolls

Research finds that sexually abused children often play with the dolls' genitalia; however, that behavior is not diagnostic, because many nonabused children do the same thing.

Rosenzweig Picture Frustration Study

After one cartoon character makes a provocative remark to another, a viewer decides how the second character should respond. This instrument, featured in the movie *A Clockwork Orange*, successfully predicts aggression in children.

Sentence Completion Test

Test takers finish a sentence, such as, "If only I could . . ." Most versions are poorly studied, but one developed by Jane Loevinger of Washington University is valid for measuring aspects of ego development, such as morality and empathy.

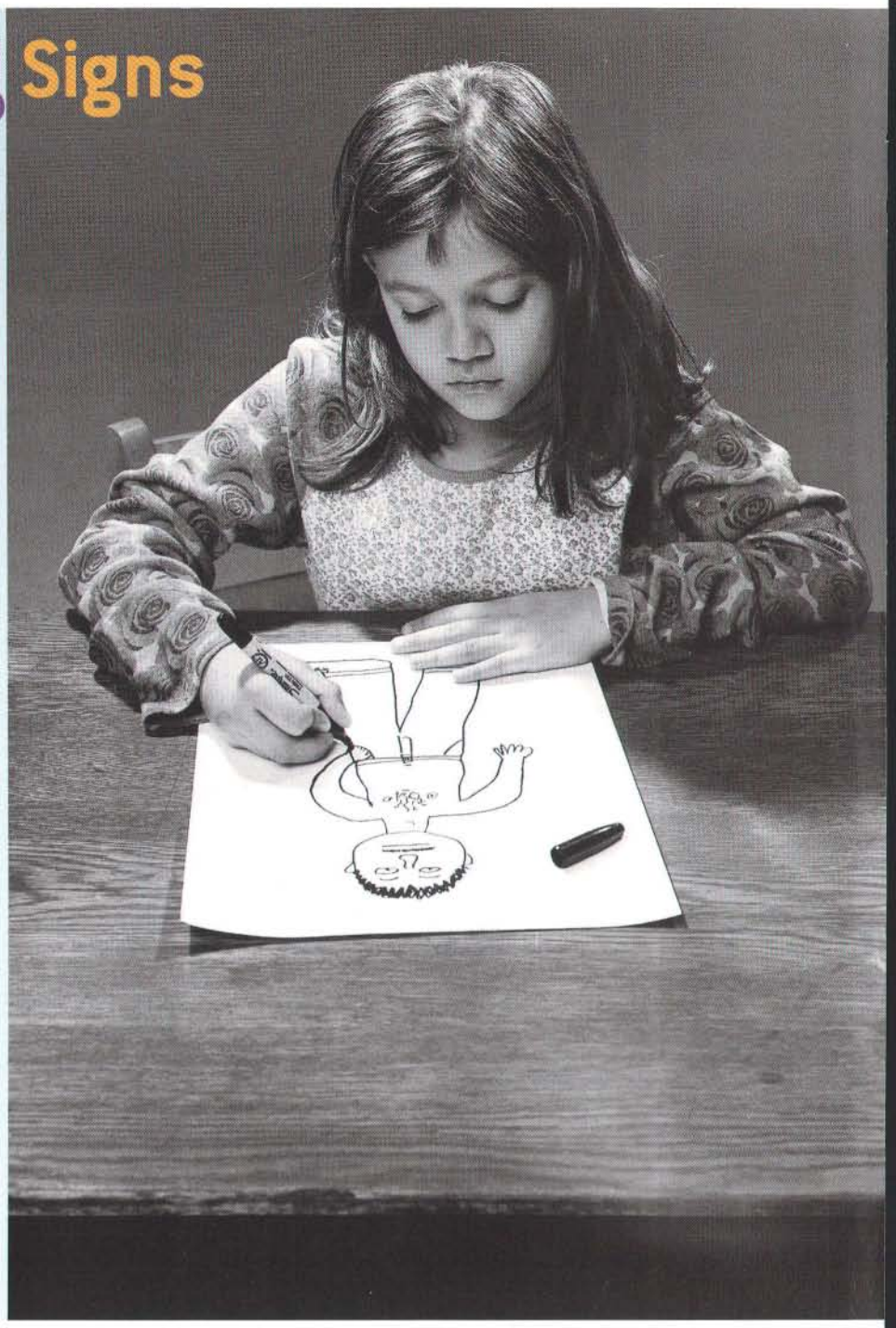
Szondi Test

From photographs of patients with various psychiatric disorders, viewers select the ones they like most and least. This technique assumes that the selections reveal something about the choosers' needs, but research has discredited it.

Even when projective methods assess what they claim to measure, they **RARELY ADD MUCH** to information that can be obtained in other, more practical ways.

HUMAN FIGURE DRAWINGS

Misleading Signs



Psychologists have many projective drawing instruments at their disposal, but the Draw-a-Person Test is among the most popular—especially for assessing children and adolescents. A clinician asks the child to draw someone of the same sex and then someone of the opposite sex in any way that he or she wishes. (A variation involves asking the child to draw a person, house and tree.) Those who employ the test believe that the drawings reveal meaningful information about the child's personality or mental health.

In a sketch of a man, for example, small feet would supposedly indicate insecurity or instability—a small head, inadequacy. Large hands or teeth would be considered signs of aggression; short arms, a sign of shyness. And feminine features—such as long eyelashes or darkly colored lips—would allegedly suggest sex-role confusion.

Yet research consistently shows that such "signs" bear virtually no relation to personality or mental illness. Scientists have denounced these sign interpretations as "phrenology for the 20th century," recalling the 19th-century pseudoscience of inferring people's personalities from the pattern of bumps on their skulls.

Still, the sign approach remains widely used. Some psychologists even claim they can identify sexual abuse from certain key signs. For instance, in the child's drawing at the right, alleged signs of abuse include a person older than the child, a partially unclothed body, a hand near the genitals, a hand hidden in a pocket, a large nose and a mustache. In reality, the connection between these signs and sexual abuse remains dubious, at best.

less accurate than graduate students at distinguishing psychological normality from abnormality.

A few global scoring systems, which are not based on signs, might be useful. Instead of assuming a one-to-one correspondence between a feature of a drawing and a personality trait, psychologists who apply such methods combine many aspects of the pictures to come up with a general impression of a person's adjustment. In a study of 52 children, a global scoring approach helped to distinguish normal individuals from those with mood or anxiety disorders. In another report, global interpretation correctly differentiated 54 normal children and adolescents from those who were aggressive or extremely disobedient. The global approach may work better than the sign approach because the act of aggregating information can cancel out "noise" from variables that provide misleading or incomplete information.

Our literature review, then, indicates that, as usually administered, the Rorschach, TAT and human figure drawings are useful only in very limited circumstances. The same is true for many other projective techniques, some of which are described in the box on the preceding page.

We have also found that even when the methods assess what they claim to measure, they tend to lack what psychologists call "incremental validity": they rarely add much to information that can

be obtained in other, more practical ways, such as by conducting interviews or administering objective personality tests. (Objective tests seek answers to relatively clear-cut questions, such as, "I frequently have thoughts of hurting myself—true or false?") This shortcoming of projective tools makes the costs in money and time hard to justify.

What to Do?

SOME MENTAL HEALTH professionals disagree with our conclusions. They argue that projective tools have a long history of constructive use and, when administered and interpreted properly, can cut through the veneer of respondents' self-reports to provide a picture of the deepest recesses of the mind. Critics have also asserted that we have emphasized negative findings to the exclusion of positive ones.

Yet we remain confident in our conclusions. In fact, as negative as our overall findings are, they may paint an overly rosy picture of projective techniques because of the so-called file drawer effect. As is well known, scientific journals are more likely to publish reports demonstrating that some procedure works than reports finding failure. Consequently, researchers often quietly file away their negative data, which may never again see the light of day.

We find it troubling that psychologists commonly administer projective instruments in situations for which their value has not been well established by multiple studies; too many people can suffer if erroneous diagnostic judgments influence therapy plans, custody rulings or criminal court decisions. Based on our findings, we strongly urge psychologists to curtail their use of most projective techniques and, when they do select such instruments, to limit themselves to scoring and interpreting the small number of variables that have been proved trustworthy.

Our results also offer a broader lesson for practicing clinicians, psychology students and the public at large: even seasoned professionals can be fooled by their intuitions and their faith in tools that lack strong evidence of effectiveness. When a substantial body of research demonstrates that old intuitions are wrong, it is time to adopt new ways of thinking. SA

HOW OFTEN THE TOOLS ARE USED

Popularity Poll

In 1995 a survey asked 412 randomly selected clinical psychologists in the American Psychological Association how often they used various projective and nonprojective assessment tools, including those listed below. Projective instruments present people with ambiguous pictures, words or things; the other measures are less open-ended. The number of clinicians who use projective methods might have declined slightly since 1995, but these techniques remain widely used.

PROJECTIVE TECHNIQUES	USE ALWAYS OR FREQUENTLY	USE AT LEAST OCCASIONALLY
Rorschach	43%	82%
Human Figure Drawings	39%	80%
Thematic Apperception Test (TAT)	34%	82%
Sentence Completion Tests	34%	84%
CAT (Children's version of the TAT)	6%	42%

NONPROJECTIVE TECHNIQUES*	USE ALWAYS OR FREQUENTLY	USE AT LEAST OCCASIONALLY
Weshler Adult Intelligence Scale (WAIS)	59%	93%
Minnesota Multiphasic Personality Inventory-2 (MMPI-2)	58%	85%
Weschler Intelligence Scale for Children (WISC)	42%	69%
Beck Depression Inventory	21%	71%

* Those listed are the most commonly used nonprojective tests for assessing adult IQ (WAIS), personality (MMPI-2), childhood IQ (WISC) and depression (Beck Depression Inventory).

SOURCE: "Contemporary Practice of Psychological Assessment by Clinical Psychologists," by C. E. Watkins et al. in *Professional Psychology: Research and Practice*, Vol. 26, No. 1, pages 54–60; 1995.

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BAR-CODE READERS

Quick Scan

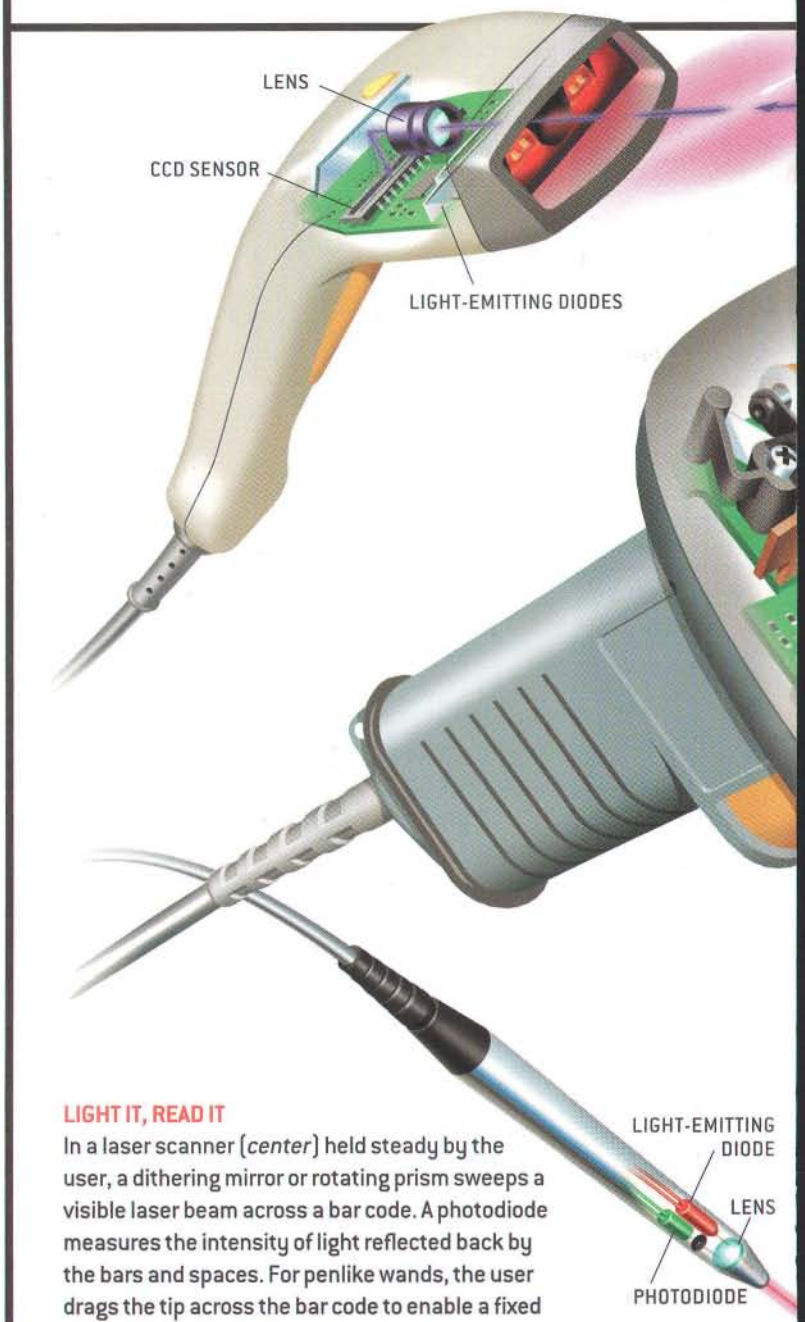
Look around your home tonight, and you may be surprised at how many items sport bar codes: groceries, magazines, mail, books, furniture, printed circuit boards inside computers, perhaps even your driver's license. Several types of bar-code readers make instant sense of these high-tech graffiti. Penlike wands are dragged across the bars of a code. Laser scanners are aimed like a gun. Charge-coupled-device (CCD) readers are held up against it. The devices illuminate codes with 645- to 690-nanometer (red) light and convert a code's image into a voltage waveform, which a decoder translates into numbers and letters for a computer or terminal. Companies such as Intermec Technologies, Metrologic and PSC sell $2 billion worth of readers every year.

Wands, common in libraries and hospitals, are the least expensive and most durable readers. They can be frustrating, however, because the operator must hold the wand against a bar code at a certain angle and move it back and forth at a consistent speed. Laser scanners such as those in grocery stores are the most widely used, although they are also the most expensive at $300 to $1,100 apiece. A typical laser can read a code from four to 16 inches away, and long-range warehouse models can reach up to 30 feet.

CCD readers create a beam with a row of light-emitting diodes (LEDs). They cost less and are more rugged than lasers, but most models must be held within six to eight inches of the bar code. They are better outdoors in sunlight and at reading low-contrast codes.

Bar-code applications continue to broaden. Aerospace manufacturers are beginning to put bar codes on airliner parts so that they can be tracked from cradle to grave, thereby preventing maintenance workers from installing old or defective parts. The auto industry is examining a similar scheme. Intermec is developing a tiny reader to empower consumers. Its miniaturized LED will read up to 100 bar codes into the memory of a cell phone or handheld computer. Shoppers could compare prices from different stores, create online shopping lists or link to the Web to view product information that manufacturers key to a code.

—Mark Fischetti



LIGHT IT, READ IT

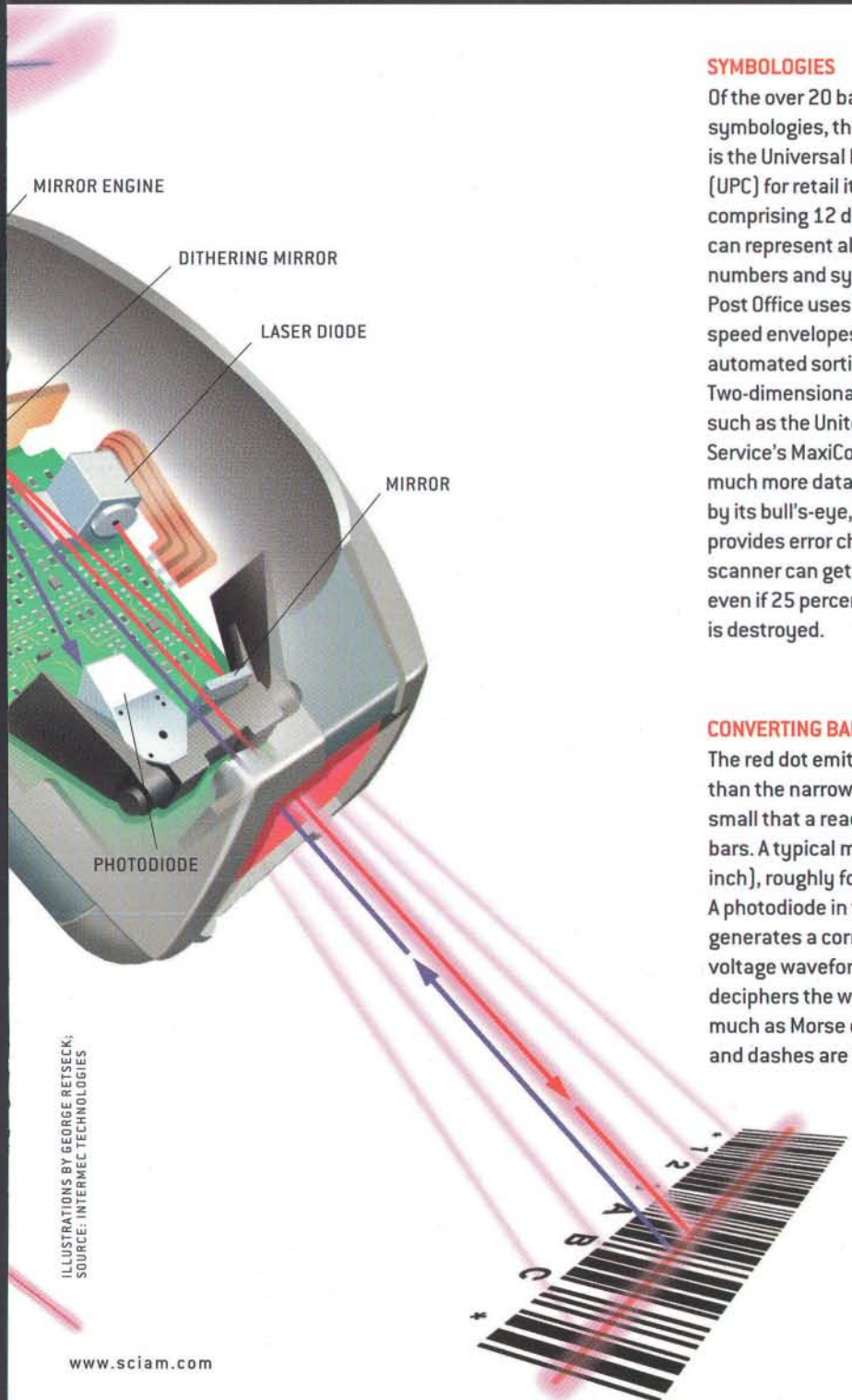
In a laser scanner (*center*) held steady by the user, a dithering mirror or rotating prism sweeps a visible laser beam across a bar code. A photodiode measures the intensity of light reflected back by the bars and spaces. For penlike wands, the user drags the tip across the bar code to enable a fixed red light to illuminate the code. Charge-coupled-device scanners have a row of tiny light-emitting diodes that illuminate a code; CCDs measure the intensity of reflected light.

DID YOU KNOW . . .

➤ **HONEY BARS** To track pollinating honeybees for a 1989 U.S. Department of Agriculture project, Sprague Ackley of Intermec Technologies crafted a three-millimeter-wide plastic bar-code label. Entomologist Stephen Buchmann refrigerated several hundred bees, then glued the codes between their wings. A laser scanner installed beside a research hive recorded each bee's comings and goings to profile their activity patterns.

➤ **ERROR RATE** Bar-code readers can record data five to seven times faster than a skilled typist can. And readers have an error rate of about one in three million characters, compared with one in 300 keystrokes for the average data-entry worker.

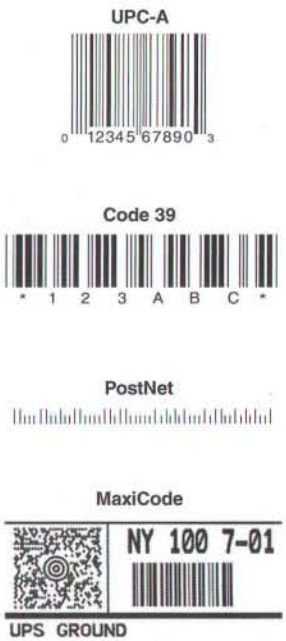
➤ **CODE MASTER** According to *The Bar Code Book*, by Roger Palmer, the concept of code scanning dates back to Wallace Flint, son of a Massachusetts grocery wholesaler. He wrote his 1932 master's thesis at Harvard University on automating supermarket checkouts. Joe Woodland and Berny Silver patented a bull's-eye code in 1949, and Girard Feissel patented a bar-segment code in 1959. IBM engineers invented the UPC, selected in the late 1960s as the first bar-code standard for retailing.



ILLUSTRATIONS BY GEORGE RETSECK; SOURCE: INTERMEC TECHNOLOGIES

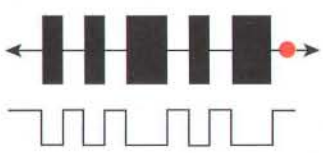
SYMBOLOGIES

Of the over 20 bar-code symbologies, the most common is the Universal Product Code (UPC) for retail items, comprising 12 digits. Code 39 can represent all ASCII text, numbers and symbols. The U.S. Post Office uses PostNet code to speed envelopes through automated sorting equipment. Two-dimensional symbologies, such as the United Parcel Service's MaxiCode, can pack in much more data. Distinguished by its bull's-eye, MaxiCode provides error checking, so a scanner can get a good read even if 25 percent of the image is destroyed.



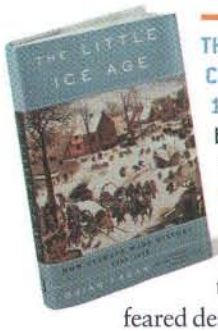
CONVERTING BARS TO VOLTAGES

The red dot emitted by a wand or laser reader is slightly smaller than the narrowest bar or space it is intended to read, yet not so small that a reading would be foiled by accidental voids in the bars. A typical minimum bar width is 13 mils (thousandths of an inch), roughly four adjacent dots on a 300-dot-per-inch printer. A photodiode in the reader senses light reflected by the code and generates a corresponding voltage waveform. A decoder deciphers the waveform much as Morse code's dots and dashes are read.



A Case Study for Global Warming

THE LITTLE ICE AGE OFFERS CLUES TO HOW OUR SOCIETY MIGHT HANDLE A MAJOR CLIMATE CHANGE **BY KEAY DAVIDSON**



THE LITTLE ICE AGE: HOW CLIMATE MADE HISTORY 1300–1850
by Brian Fagan
Basic Books, New York ($26)

In the mid-17th century in the Swiss Alps, the inhabitants of Les Bois feared destruction by an unusual enemy: a glacier. The immense sheet of ice was slowly advancing through mountain passes to their village. In those days no one suspected that the danger was at least partly connected with the sun—specifically, with a curious absence of dark splotches on its shiny surface 93 million miles away. Instead they assumed what any devout European peasant of those days would have assumed, namely, that God was angry and punishing humanity for its sins. The bishop of Geneva took action: he led 300 locals to the village and blessed the glacier. Some years afterward a warming trend forced it into retreat.

The Les Bois incident was one of the odder episodes of the so-called Little Ice Age, a prolonged cold snap that lasted many decades and possibly more than five centuries (experts disagree). Nowadays scientists are paying growing attention to the Little Ice Age for two reasons. First, it might shed light on subtle links between solar activity and terrestrial climate; curiously, sunspots largely disappeared between 1645 and 1705. Scientists have debated for years whether the sunspot drought caused terrestrial cooling—and if so, why. If the Little Ice Age really lasted between 1300 and 1850 (as some scientists believe), then the cooling must have had several causes other than a transient lapse in solar activity.

Second, the Little Ice Age offers a well-documented case study of the impact of major climate change on a thriving civilization, in this case preindustrial Europe. How Newton's and Voltaire's generations handled the Little Ice Age provides hints of how our society might handle a different episode of climate change now well under way: global warming. We may not handle it terribly well, judging by the historical lessons of this book by Brian Fagan, a professor of archaeology at the University of California at Santa Barbara.

In 246 smoothly written pages, Fagan tells how different societies were altered by major climate changes from the Middle Ages to the 20th century. His book could do for the historical study of climate what Michel Foucault's classic *Madness and Civilization* did for the historical study of mental illness: make it a respectable subject for scholarly inquiry. True, the climate has been explored for decades by other scholars, notably Emmanuel Le Roy Ladurie and Hubert H. Lamb. But it never acquired much of a following among historians. One reason is historians' sour memories of the heyday of "climatic determinism," a minor scholarly fad of the early 20th century whose champions, notably the explorer Ellsworth Huntington, badly overstated the importance of climate change in spawning and destroying civilizations. Today

DETAIL FROM *The Census at Bethlehem*, by Pieter Brueghel the Elder (circa 1525–69)

scholars—including Fagan—agree that the fates of nations are usually too complex to be blamed solely on the fluctuations of barometers or on temperature variations recorded in tree rings and ice cores. Unlike Huntington, Fagan convinces precisely because he refuses to overstate his case. He emphasizes that although weather partly accounts for historical traumas such as the French Revolution and the Irish potato famine, these events also have many other social, economic and political causes.

Fagan's multicausal analysis is especially welcome at this time, as we inhabitants of the early 21st century confront the threat of global warming. The scientific evidence for global warming is strong, yet an amazing number of intelligent people still question its reality. Why? I suspect it is because sometimes emotional media coverage encourages them to think that global warming will arrive suddenly, announcing itself via some overnight cataclysm—say, the submerging of several Pacific islands or a hurricane of unprecedented ferocity that slaughters thousands of Floridians. (Some dreadful science-fiction movies have implied that global warming will arrive in exactly this manner.)

But as Fagan's historical case studies reveal, most big climate changes don't strike so quickly. To date, the climatic "signal" of global warming has been subtle, forcing scientists to use complex computer programs to identify it against meteorological background noise. In the absence of a more clear-cut signal, certain politicians, oil companies and other interest groups have argued for doing little or nothing about the problem.

They should read Fagan's book. Its unspoken message is clear: when the atmosphere prepares to clobber humanity, it walks softly but carries a big stick. The time to act is now, however cloudless the horizon may appear. SA

Keay Davidson is a science writer at the San Francisco Chronicle *and author of* Carl Sagan: A Life *(John Wiley & Sons, 1999).*

THE EDITORS **RECOMMEND**

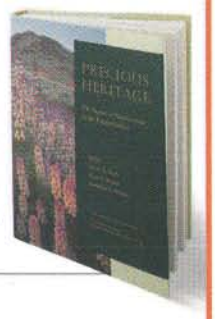
MAUVE: HOW ONE MAN INVENTED A COLOR THAT CHANGED THE WORLD

by Simon Garfield. W. W. Norton, New York, 2001 ($23.95)

The man was William Perkin (1838–1907), an English chemist. The color was mauve, which he discovered by accident when he was 18. "While working on an experiment, I failed," he said many years later, "and was about to throw a certain black residue away when I thought it might be interesting." The experiment was an effort to make synthetic quinine, and the black residue was coal tar. Perkin's accidental discovery gave rise to industrial aniline and the modern synthetic-dye industry, as well as to a number of other processes employing coal-tar derivatives. It also, Garfield says, "affected the whole nature of scientific investigation: for the first time, people realized that the study of chemistry could make them rich." Perkin became rich and received a knighthood. Garfield, a Londoner who writes about science, tells the Perkin and aniline stories well.

PRECIOUS HERITAGE: THE STATUS OF BIODIVERSITY IN THE UNITED STATES

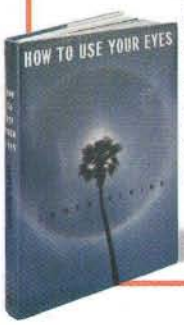
edited by Bruce A. Stein, Lynn S. Kutner and Jonathan S. Adams. Oxford University Press, 2000 ($45)



This comprehensive (and extremely handsome) book analyzes patterns of biological diversity in the U.S.—a vast area that stretches from above the Arctic Circle to below the Tropic of Cancer. The country's 200,000 species (double previous counts) are not faring well. Roughly one third are at risk; 500 are already extinct or missing. *Precious Heritage* identifies the first ever "hot spots" where conservation efforts would be especially important, and challenges us to consider the scale of habitat conservation that will be needed to protect entire ecological systems. Some of the leading experts on the subject, E. O. Wilson writes in the foreword, "invite us to turn inward, not by abandoning global conservation but by conserving our own fauna and flora in a manner that will set a shining example for the rest of the world."

HOW TO USE YOUR EYES

by James Elkins. Routledge, New York, 2000 ($28)



Elkins, associate professor of art history, theory and criticism at the School of the Art Institute of Chicago, says that our eyes are too good for us, taking in so many things that we tend to focus only on what is important at the moment. "What happens if we stop and take the time to look more carefully? Then the world unfolds like a flower, full of colors and shapes that we had never suspected." Whereupon he takes close looks at 31 things and at "nothing." (Looking at nothing, he observes, turns out to be quite hard to do: "Our eyes will not stop seeing, even when they have to invent the world from nothing.") Among the 31 things are an old painting (not for its picture but for its craquelure, which reveals much about the history of the painting), an x-ray, the periodic table and a sunset. The result is a book that is visually stunning and mentally stimulating.

All the books reviewed are available for purchase through www.sciam.com

War and Peace among the Pinnipeds

VISITING THE WILDLIFE OF AÑO NUEVO BY MARGUERITE HOLLOWAY

It is not often that you can get close to a red-necked, huge-nosed, bellowing, two-and-a-half-ton, 14-foot-long behemoth and his cronies—particularly if he is in the midst of courtship or fighting off a foe. But at Año Nuevo State Reserve, a 4,000-acre park on California's rough and rocky coast, such privileged views are common. Thousands of northern elephant seals haul out along the beaches at different times of year, providing visitors with an up-close-and-personal look at the lives of these mammoth creatures and of other ocean-dwelling mammals as well.

Año Nuevo is a beautiful spot, regardless of what you come to see or when you come to see it. The elephant seal beaches, and one of the few remaining true sand dunes in this region, lie at the far end of long, wide fields and some shrubby enclaves—roughly a mile and a half from the entrance of the reserve. This low vegetation is a raptor lover's haven, hunted by northern harriers, red-tailed hawks, Cooper's hawks, golden eagles, white-tailed kites and American kestrels, among others. Indeed, because of the varied habitats in the park—and because it falls along the Pacific flyway, a major migration route—some 240 species of birds can been found at Año Nuevo over the course of the year.

As you walk through the brushy terrain toward the beaches, you can see the rugged coastal cliffs curving down to the south toward Santa Cruz. Wildflowers—including California poppy and Indian paintbrush—start to bloom on the eastern side of the reserve in late February and early March; the color sweeps through the fields over the next few months, reaching the coast by June.

ELEPHANT SEAL colony at Año Nuevo became established in the 1960s. The seals had been nearly wiped out in the previous century by hunters seeking blubber for oil. Protected since the 1920s, elephant seals now thrive along the Pacific coast.

Just half a mile offshore—off-limits to visitors but open to researchers studying great white sharks, elephant seals and other creatures—sits Año Nuevo Island. Until the late 1700s, when the sea finally had its way, it was attached to the mainland. Now the ruins of a lighthouse and its keeper's Victorian-style quarters are overrun by wildlife. According to the reserve's docents, a few of the thousands of Steller and California sea lions that inhabit the island sometimes make it up the stairs and into the bathtub on the second floor of the main house. The island is also frequented by harbor seals, sea otters, rhinoceros auklets, brown pelicans and three species of cormorant. Visitors looking off the coast during March and April can observe gray whales making their annual northward migration from

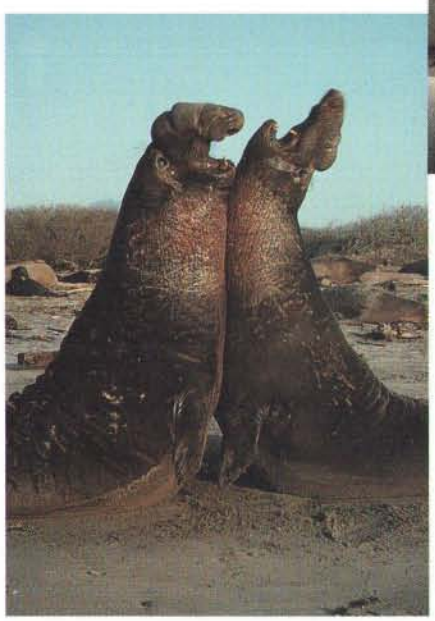
Baja California to their summer feeding sites in the northern Pacific. (Another good place to spot them is from Pigeon Point Lighthouse, just a few miles north of Año Nuevo.)

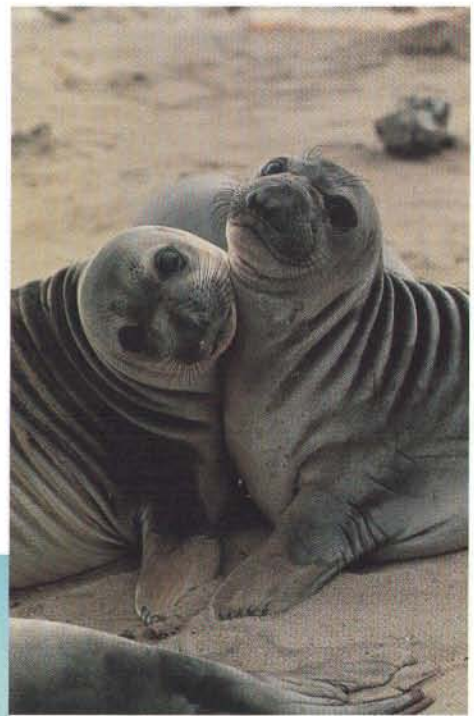
Despite these many attractions, Año Nuevo is best known for its colony of elephant seals, the largest group in the Northern Hemisphere. For that reason, one of the most exciting times to visit the reserve is in the winter and early spring, between mid-December and the end of March. During these months the females come in from the ocean to give birth and the males fight over them and assemble harems for mating. An alpha bull will lie, like a huge brown boulder, amid his entourage of dozens of females, moving his bulk surprisingly quickly only when another male—and there are often many lurking around the edges of the group—gets too close. Around him the females, svelte at about a mere ton, toss sand on themselves and give birth, often in just 10 minutes and with hardly a noise. Around them lie the newborn pups, darker in color, reflexively tossing sand on themselves as well. And amid this throng of massive seals stalk gulls and other seabirds looking for bits of nutritious placenta.

By the end of January, after the pups have been born, the fighting among the males begins in earnest. The peak for mating is Valentine's Day.

By the end of January, after the pups have been born, the fighting among the males begins in earnest. "The peak for mating is Valentine's Day," says Frank S. Balthis, a longtime Año Nuevo ranger. The thick skin around their necks becomes bloody with battle. The pups try to stay clear, as they can be crushed in the rushing fights and in the mating spree. In March the females head back to sea, exhausted and depleted from giving birth and mating. Although they may carry a fertilized egg, it will not implant for another three months or so, until they have been able to eat enough to sustain it. In April and May the females return by the thousands to molt on the beaches; the males come back between May and August to do the same. (In the fall, the yearlings and juvenile males return to hang out and practice fighting.)

Males and females continue their separate ways while at sea. Researchers from the University of California at Santa Cruz have recently determined that the males for the most part swim north to southern Alaska and the Aleutian Islands, where they visit foraging grounds. Radiotransmitter studies have revealed that the animals can dive as deep as 5,000 feet—the record for all seals—and sometimes stay under for an hour or so. In these chilly waters, they feed on fatty bottom fish and on skates and rays. The females, who have lower caloric requirements, tend to spread out in the open ocean, not in any particular areas, and to feed on squid as they travel.





PROBOSCIS reaches its full length of about 30 centimeters in its relaxed state by the time male elephant seals are eight years old. It may serve to amplify the enginelike roar of the older males (*left*). Young seals (*above*) must stay clear of fighting males to avoid getting crushed.

Año Nuevo reserve is 55 miles or so south of San Francisco, an easy drive along Highway 1. During the winter months, visitors must make reservations for docent-led tours to watch the elephant seals giving birth, fighting and mating (call 800-444-4445 or 650-879-2033). During the rest of the year, reservations are not needed, but hiking permits are required for access to some areas where wildlife assemble. For general information, call 650-879-0227 or 650-879-2025 or look up the reserve online at www.anonuevo.org. There are several other parks near Año Nuevo, including the 18,000-acre Big Basin Redwoods State Park, with its centuries-old redwoods, and Butano State Park. And there is excellent artichoke soup and sourdough bread to be had at Duarte's Tavern in Pescadero.

Marguerite Holloway is a contributing editor for Scientific American.

Something Fishy

BY DENNIS E. SHASHA

The resort was far too charming a place for such a senseless, smelly crime. Seven rustic bungalows, four of them on a lagoon (A through D), two on the oceanfront (F and G) and one in the middle (E), were connected by pathways as shown on the map below. A fisherman saw a sinister-looking man carrying a large basket approach the resort from the lagoon and sneak into one of the bungalows bordering that body of water. The man then stalked along the pathways from one bungalow to the next, leaving rotting fish everywhere.

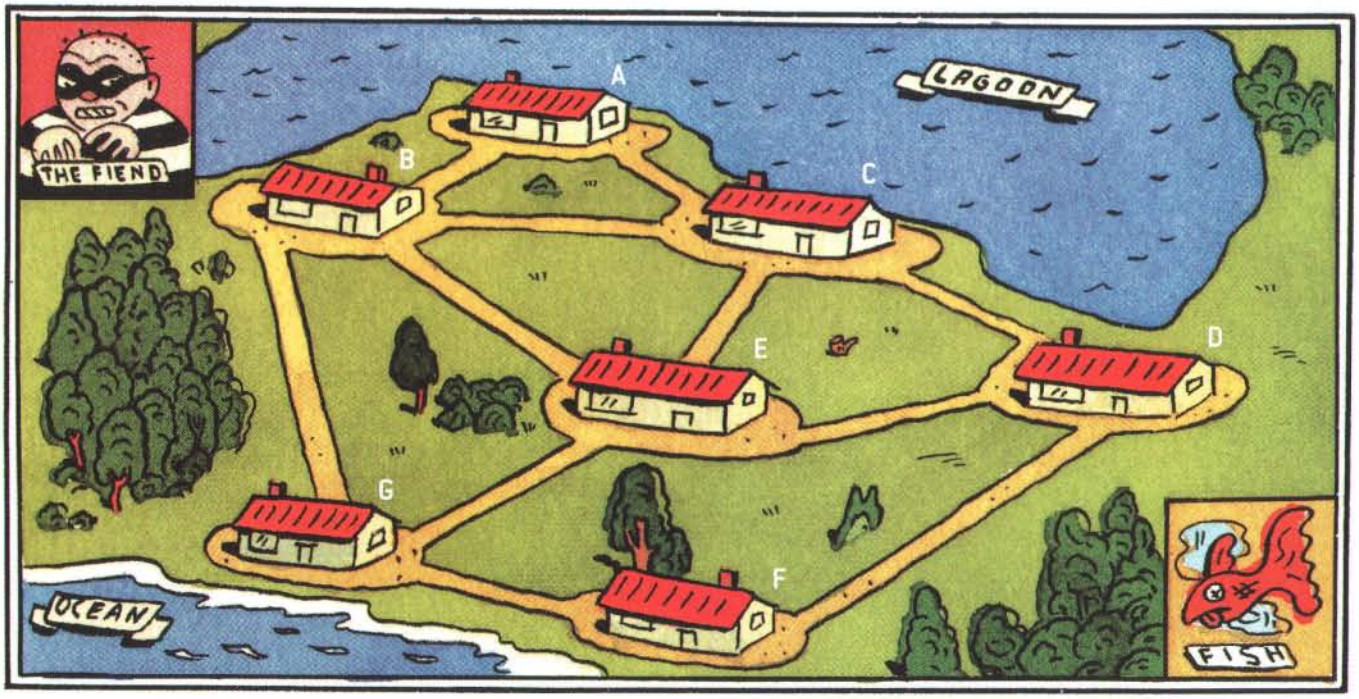
Police detectives determined from a set of muddy footprints that the vandal had traveled along each pathway exactly once. The detectives saw no footprints leading away from the resort, so they concluded that the fishy character was still hiding in one of the bungalows. Unfortunately, the footprints on the pathways were so indistinct that the detectives couldn't tell the direction in which they pointed. What is more, the fisherman couldn't remember which of the four bungalows on the lagoon the criminal had first entered. The police were therefore unable to retrace the fiend's route—all they knew was that he'd never walked the same pathway twice.

Your assignment is to find the one bungalow in which the fish vandal must be hiding. A branch of mathematics called graph theory may help you deduce the answer: the map below can be thought of as a graph, which is a collection of nodes (represented here by the bungalows) linked by edges (the pathways). The solution to the problem will appear in next month's column. SA

Dennis E. Shasha, a professor of computer science at the Courant Institute of New York University, creates and solves puzzles for a living. Two books of his puzzles have appeared: The Puzzling Adventures of Dr. Ecco *(W. H. Freeman, 1988; Dover, 1998) and* Codes, Puzzles, and Conspiracy *(W. H. Freeman, 1992).*

Answer to Last Month's Puzzle:
One way to keep the board from tipping is to remove the packages from their positions in this order: position 1 (10 kilograms), 8 (5 kg), –6 (8 kg), 5 (9 kg), –8 (4 kg), 8 (10 kg), –3 (10 kg), –4 (5 kg), 2 (9 kg), –2 (2 kg), 3 (3 kg), –3 (2 kg), 5 (1 kg), –6 (1 kg) and 2 (5 kg).

Web Solution:
For a peek at the answer to this month's problem, visit www.sciam.com



Drink and Be Merry

MUMM'S MIGHT HAVE BEEN THE WORD IF THIS STORY HAD REMAINED SOLELY ABOUT WINES. BUT WHEN LIFE HANDS YOU LEMONS, YOU DON'T NEED SOUR GRAPES **BY STEVE MIRSKY**

This was going to be a robust little column with a puckish attitude and some flinty, if not downright acidic, notes. I was all set to write about a fascinating lecture on the language of wine given at the annual meeting of the American Association for the Advancement of Science, held in San Francisco in February. Of course, vintage wine verbiage has long been the subject of crisp yet tart lampooning. Nevertheless, the philosopher of language Ferdinand de Saussure did argue, probably between sips of sauvignon, that "the linguist has an interest in everything that touches the tongue." So a specific consideration of wine words is certainly appropriate, especially in light of the problems inherent in describing flavors.

I mean, if I write that the Pentagon building is a pentagon, that pretty much covers all five sides of the issue. But if I say that a wine is prickly, well, we're just getting started. For example, the word "assertive" is a compliment when used to describe a wine, whereas "aggressive" is an insult. I was surprised to learn this, although a female friend told me, "See, if you were a woman, you'd have known that already."

Anyway, as I say, I was all set to write a disciplined, balanced and zestful column about the language of wine (enough of which has now been well crafted to get my travel expenses reimbursed, I introspectively hope). Then came a rare, stop-the-presses moment, the presses that print the magazine, not the kind that squeeze grapes: a scientific study was published on humor—a functional MRI analysis of where jokes get processed in the brain. Actual neuroscientific research on humor must therefore stem the flight of any wine talk in this, America's premier science-mad magazine. (What, me Wernicke?)

The researchers, Vinod Goel (amazingly, not a wine) of Toronto's York University and Raymond Dolan of London's Royal Free Hospital School of Medicine, cracked up 14 volunteers who allowed their brains to be scanned during the kidding. The write-up, in *Nature Neuroscience*, revealed that the very captive audience—*you* try to run with your brain being imaged—was exposed to two basic types of jokes: puns and the good kind. Or technically, phonological jokes and semantic jokes.

The very captive audience—*you* try to run with your brain being imaged—was exposed to two basic types of jokes: puns and the good kind.

The article gives examples of each. Phonological: "Why did the golfer wear two pairs of pants? He got a hole in one." Semantic: "What do engineers use for birth control? Their personalities." Not surprisingly, it turns out that processing semantic jokes involves parts of the brain known to be involved in language processing, whereas puns get the attention of brain sections concerned with speech sounds. And a good one-liner of any kind really lights up the old medial ventral prefrontal cortex. Oddly enough, wine connoisseurs show similar sensitivity, evidenced by the old observation, "I'd rather have a free bottle in front of me than a prefrontal lobotomy."

The two jokes above were the only ones cited in the article. But Goel was kind enough to e-mail me the entire set used in the study. Here come some samples:

Joke: "What do you give the man who has everything? Antibiotics."

He'd probably love to get this whole antitrust thing off his back, too.

Joke: "Where can you find a turtle with no legs? Right where you left him."

Well, I don't know about that, but I do know that if you have a dog with no legs, no matter what you call him, he still won't come.

Joke: "If you have spots before your eyes, shouldn't you see a doctor? No, only spots."

George W. Bush really has a dog named Spot. That's kind of funny.

Joke: "Which side of a dog usually has the most hair? The outside."

Ah, yes, the hair of the dog, right back where we came in. Which leads us to:

Joke: "What did the grape say when he was sat on? Nothing, he just let out a little whine." SA

How do squid and octopuses change color?

—W. Kang, New York City

Ellen J. Prager, assistant dean of the University of Miami's Rosenstiel School of Marine and Atmospheric Science and author of *The Oceans* (McGraw-Hill, 2000), offers this explanation:

A number of cephalopods—the group of animals that includes octopuses, squid and cuttlefish—are skilled in the art of color change, which can be used for camouflage or to startle and warn potential predators in their undersea realm. Many of these creatures have special pigment cells called chromatophores in their skin. By controlling the size of the cells, they can vary their color and even create changing patterns. Chromatophores are connected to the nervous system, and their size is determined by muscular contractions. The cephalopods also have extremely well developed eyes, which are believed to detect both the color and intensity of light. Using their excellent eyesight and chromatophores, cephalopods camouflage themselves by creating color patterns that closely match the underlying seafloor. In squid, color changes also occur when the animal is disturbed or feels threatened.

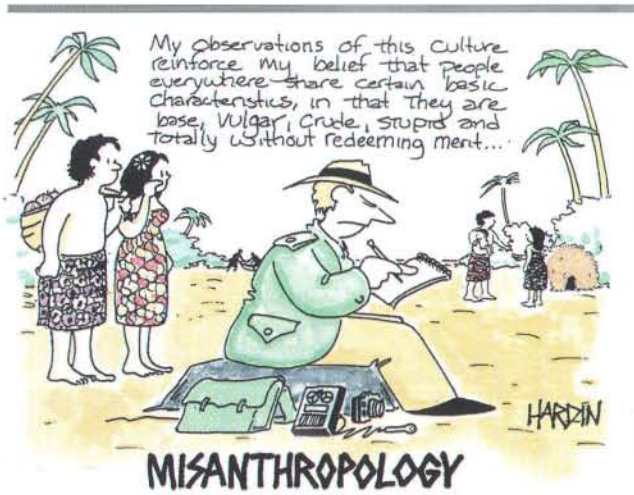
In addition to color control, many squid can produce light and control its intensity. Some marine creatures are believed to use bioluminescence to confuse predators, others may stun their prey, and some use it as a decoy to facilitate escape or as a lure to attract the unwary. It may also offer a means of communication in the dim midwater or twilight region of the sea.

Squid and other marine creatures create light in much the same way that a common firefly lights up or the same way that the popular plastic green glow-sticks work. To get a glow-stick to "glow," it is bent. This causes the two chemicals inside to mix and react, yielding a third substance that gives off light. Within an organism's special light-producing cells (called photocytes) or organs (photophores), essentially the same thing happens. A substance called luciferin reacts with oxygen in the presence of an enzyme, luciferase. A new molecule forms when the reaction is complete, and in the ocean it typically glows blue to green in color.

> *"Logical consequences are the scarecrows of fools and the beacons of wise men."*
>
> —Thomas Henry Huxley

In some organisms the photophores are simple glandular cups. In others, they are elaborate devices with lenses for focusing, a color filter, or an adjustable flap that serves as an off/on switch. Squid that have both photophores and chromatophores within their skin can control both the color and the intensity of light produced. Research has also revealed that within some squid and fish, bioluminescent light may be produced by bacteria that live inside the animal's light organs. SA

For answers to many other questions, visit Ask the Experts (www.sciam.com/askexpert).



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The 2002 King Faisal International Prize for Medicine and Science

Invitation to Nominate

جائزة الملك فيصل العالمية
King Faisal International Prize

The General Secretariat of the King Faisal International Prize is pleased to invite universities, scientific societies, research centres, and other learned circles throughout the world to nominate candidates for the year 2002 Prize for Medicine and Science. Nominees should be widely recognized for outstanding contributions to the following:

Topic for Medicine:

Pathophysiology of Chronic Heart Failure

Topic for Science:

Mathematics

Conditions and Requirements:

- Nominated works must:
  - **a)** be original, published, and represent a contribution of the highest distinction;
  - **b)** benefit mankind and advance scientific knowledge.
- Nominations must be submitted by official scientific nominators and not by individuals or political parties.
- Nominations must include:
  - **a)** an official letter of nomination detailing the scientific justification for every nominee separately;
  - **b)** a typed CV detailing the nominee's academic background and experience, and listing all the nominee's published works;
  - **c)** The total number of nominated papers and books should not exceed **twenty** (20) titles; the following should be submitted:
    - One (1) original copy of each nominated **Paper**;
    - Six (6) copies of each nominated Book;

    Nominated books and papers will not be returned
  - **d)** Three (3) recent color photos on matt card 4"x6" ;
  - **e)** one completed form for each nominee. ***Form may be duplicated if there is more than one candidate***

Items (b,c,d,e) may be submitted by the nominee

The Prize Consists of:

- A certificate written in Diwani calligraphy and presented in a leather folder, describing the work for which the winner is awarded the Prize;
- A Commemorative 24-carat, 200-gram gold medallion;
- SR 750,000 (US$ 200,000).
  Joint winners share the cash prize

General Remarks:

- In order for nominees to qualify, all conditions must be fulfilled.
- Required documentation must be received by the General Secretariat of the King Faisal International Prize no later than **31 May 2001**.
- Winners will be announced in **January 2002** and will be honored at an official ceremony later in the year in Riyadh.
- The decision of the Prize's Selection Committee is final.
- Please send nominations by airmail to:

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King Faisal International Prize
Al-Khairia Building - King Fahd Road
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Saudi Arabia

Tel: (+966 1) 465 2255
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Note: The Form can be obtained from the General Secretariat of the King Faisal International Prize on the above address

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